Testing of New Bridge Rail and Transition Designs

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16. Abstract

The objectives of this study were to develop safer bridge rail and transition designs and to improve design guidelines. Ten bridge railings and two transitions were designed, tested, and evaluated in accordance with American Association of State Highway and Transportation Officials (AASHTO) requirements. The railings were designed using ultimate strength procedures and collision forces from earlier research. Design procedures, railing designs, and test results are presented. All designs demonstrated acceptable collision performance.

This volume is the first in a series. The other volumes in the series are: Volume II: Appendix A, "Oregon Side Mounted Bridge Railing;" Volume III: Appendix B, "BR27D Bridge Railing;" Volume IV: Appendix C, "Illinois 2399-1 Bridge Railing;" Volume V: Appendix D, "32-in (813-mm) Concrete Parapet Bridge Railing;" Volume VI: Appendix E, "32-in (813-mm) New Jersey Safety Shape;" Volume VII: Appendix F, "32-in (813-mm) F-Shape Bridge Railing;" Volume VIII: Appendix G, "BR27C Bridge Railing;" Volume IX: Appendix H, "Illinois Side Mount Bridge Rail;" Volume X: Appendix I, "42-in (1.07-m) Concrete Parapet Bridge Railing;" Volume XI: Appendix J, "42-in (1.07-m) F-Shape Bridge Railing;" Volume XII: Appendix K, "Oregon Transition;" Volume XIII: Appendix L, "32-in (813-mm) Thrie-Beam Transition;" and Volume XIV: Appendix M, "Axial Tensile Strength of Thrie and W-Beam Terminal Connectors."

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PREFACE

The study reported herein was sponsored by the Federal Highway Administration, 23 States, and the District of Columbia. It was managed by a panel of representatives from those agencies. The panel, as a group, selected existing designs and identified new designs of railing/transitions to be studied and evaluated. Participating agencies and their representatives are listed below.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
	AREA			
in²	square inches	645.2	square millimeters	mm²
ft²	square feet	0.093	square meters	m²
yd²	square yards	0.836	square meters	m²
ac	acres	0.405	hectares	ha
mi²	square miles	2.59	square kilometers	km²
	VOLUME			
fl oz	fluid ounces	29.57	milliliters	ml
gal	gallons	3.785	liters	l
ft³	cubic feet	0.028	cubic meters	m³
yd³	cubic yards	0.765	cubic meters	m³

NOTE: Volumes greater than 1000 l shall be shown in m³.

Symbol	When You Know	Multiply By	To Find	Symbol
	MASS			
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celcius temperature	°C
	ILLUMINATION			
fc	foot-candles	10.76	lux	l
fl	foot-Lamberts	3.426	candela/m²	cd/m²
	FORCE and PRESSURE or STRESS			
lbf	poundforce	4.45	newtons	N
psi	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
	AREA			
mm²	square millimeters	0.0016	square inches	in²
m²	square meters	10.764	square feet	ft²
m²	square meters	1.195	square yards	yd²
ha	hectares	2.47	acres	ac
km²	square kilometers	0.386	square miles	mi²
	VOLUME			
ml	milliliters	0.034	fluid ounces	fl oz
l	liters	0.264	gallons	gal
m³	cubic meters	35.71	cubic feet	ft³
m³	cubic meters	1.307	cubic yards	yd³
	MASS			
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg	megagrams	1.103	short tons (2000 lb)	T
	TEMPERATURE (exact)			
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F
	ILLUMINATION			
lx	lux	0.0929	foot-candles	fc
cd/m²	candela/m²	0.2919	foot-Lamberts	fl
	FORCE and PRESSURE or STRESS			
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	psi

* SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.

(Revised August 1992)

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CHAPTER 1: INTRODUCTION

Objectives of the study were to develop safer bridge rail and transition designs and to improve design guidelines.

At the beginning of the study, the 13th edition (1983) of AASHTO's *Standard Specifications for Highway Bridges* and NCHRP *Report 230* were the current documents governing design and testing of bridge railings and transitions.[1,2] FHWA was in the process of developing enhanced guidelines for designing and testing bridge railings. That effort was completed in 1989 and resulted in *Guide Specifications for Bridge Railings* (1989).[3] Two additional research studies related to this subject were performed during this time period. They was an NCHRP study to revise testing procedures and requirements in NCHRP *Report 230* (NCHRP Project 22-7) and a study to evaluate the warrants portion of the 1989 guide specifications (NCHRP Project 22-8).[2,4,5]

Also, during this time, NCHRP study 12-33 to develop Load and Resistance Factor Design (LRFD) bridge design specifications and commentary was performed.[6]

In this collective work, many sets of requirements for designing, testing, test procedures, test vehicles, and performance (or service) levels were proposed and considered. As a result, not all testing in the study reported herein was performed to a unique set of test conditions. However, all railing designs were eventually tested to conditions recommended in the 1989 guide specifications.[3]

At the beginning of the study, drawings of bridge railing systems being used by all States were collected by FHWA. More than 160 railing designs (although some were quite similar) were identified. These designs plus others proposed by research agencies and private industry were reviewed to obtain background information for use in this study.

Various degrees of analysis and evaluation of many designs were performed by the panel and the researchers. A total of 11 railings and 2 transitions were analyzed/designed, tested, and evaluated in detail. This resulted in a collection of proven railing/transition designs which meet requirements of the 1989 guide specifications.[3]

CHAPTER 2. PERFORMANCE LEVELS AND DESIGN REQUIREMENTS

The 1989 guide specifications sets forth three performance levels for bridge railings.[3] Those performance levels along with their respective crash test conditions and evaluation criteria are given in table G2.7.1.3A of that publication which is reproduced in table 1. The 1989 guide specifications was developed over a period of time prior to 1989.[3] During its development, many proposed performance levels, defined in terms of test conditions, were considered. The February 1987 draft of the guide specification included the following proposed test conditions:

Performance Level One (PL1)	5,400 lb | 45 mi/h | 20 deg
	(2 452 kg | 72.4 km/h | 20 deg)
Performance Level Two (PL2)	5,400 lb | 65 mi/h | 20 deg
	(2 452 kg | 104.6 km/h | 20 deg)
Performance Level Three (PL3)	40,000 lb | 60 mi/h | 15 deg
	(18 160 kg | 96.5 km/h | 15 deg)
Performance Level Four (PL4)	80,000 lb | 55 mi/h | 15 deg
	(36 320 kg | 88.5 km/h | 15 deg)

The 5,400-lb (2 452-kg) vehicle was a pickup truck. The 40,000-lb (18 160-kg) vehicle was an intercity bus and the 80,000-lb (36 320-kg) vehicle was a tractor with van type trailer.

In January 1988, proposed testing requirements were changed to those shown in the final version of the 1989 guide specifications (table 1).[3] Design forces for performance levels of the 1989 guide specifications are discussed below.[3]

For PL1, the test with a 5,400-lb (2 452-kg) pickup truck traveling at 45 mi/h (72 km/h) with an impact angle of 20 degrees is used to evaluate the strength and height of a railing. For these test conditions, the short duration (.050 s) collision force imposed on a rigid bridge railing is about 30 kips (133 kN). The required minimum height of the resultant of resisting force provided by the railing to prevent the vehicle rolling over the railing is at or somewhat below the center-of-gravity of the test vehicle. Height to the center-of-gravity of a typical empty pickup is at about 26 in (660 mm) and the empty weight is about 4,600 lb (2 088 kg). Onboard instrumentation used in tests increases the weight, and ballast (fixed to the vehicle) is typically used to adjust the test inertia weight to 5,400 lb (2 452-kg). The ballast is positioned to provide a center-of-gravity of the total mass at 27 in (690 mm) above the ground. The recommended design force of 30 kips (133 kN) used for PL1 railings is a uniformly distributed line force 42-in (1.07-m) long located at least 24 in (610 mm) above the roadway surface.

For PL2, the test with an 18,000-lb (8 172-kg) single unit truck traveling at 50 mi/h (80 km/h) with an impact angle of 15 degrees is used to evaluate the strength and height of a railing. For these test conditions, the short duration (.050 s) collision force imposed on a rigid bridge railing is about 56 kips (249 kN). The required minimum height of the resultant

Table 2. Bridge railing performance levels and crash test criteria.
(Exerpt from 1989 AASHTO *Guide Specifications for Bridge Railings*)[3]

	TEST SPEEDS—mph[1,2]			
	TEST VEHICLE DESCRIPTIONS AND IMPACT ANGLES			
PERFORMANCE LEVELS	Small Automobile $W = 1.8$ Kips $A = 5.4' \pm 0.1'$ $B = 5.5'$ $H_{cg} = 20'' \pm 1''$ $\theta = 20$ deg.	Pickup Truck $W = 5.4$ Kips $A = 8.5' \pm 0.1'$ $B = 6.5'$ $H_{cg} = 27'' \pm 1''$ $\theta = 20$ deg.	Medium Single-Unit Truck $W = 18.0$ Kips $A = 12.8' \pm 0.2'$ $B = 7.5'$ $H_{cg} = 49'' \pm 1''$ $\theta = 15$ deg.	Van-Type Tractor-Trailer[4] $W = 50.0$ Kips $A = 12.5' \pm 0.5'$ $B = 8.0'$ $H_{cg} =$ See Note 4 $R = 0.61 \pm 0.01$ $\theta = 15$ deg.
PL-1	50	45		
PL-2	60	60	50	
PL-3	60	60		50
CRASH TEST EVALUATION CRITERIA[3] Required	a, b, c, d, g	a, b, c, d	a, b, c	a, b, c
Desirable[5]	e, f, h	e, f, g, h	d, e, f, h	d, e, f, h

Notes:

1. Except as noted, all full-scale tests shall be conducted and reported in accordance with the requirements in NCHRP Report No. 230. In addition, the maximum loads that can be transmitted from the bridge railing to the bridge deck are to be determined from static force measurements or ultimate strength analysis and reported.

2. Permissible tolerances on the test speeds and angles are as follows:

   Speed   −1.0 mph   +2.5 mph
   Angle   −1.0 deg.   +2.5 deg.

   Tests that indicate acceptable railing performance but that exceed the allowable upper tolerances will be accepted.

3. Criteria for evaluating bridge railing crash test results are as follows:

   a. The test article shall contain the vehicle; neither the vehicle nor its cargo shall penetrate or go over the installation. Controlled lateral deflection of the test article is acceptable.

   b. Detached elements, fragments, or other debris from the test article shall not penetrate or show potential for penetrating the passenger compartment or present undue hazard to other traffic.

   c. Integrity of the passenger compartment must be maintained with no intrusion and essentially no deformation.

   d. The vehicle shall remain upright during and after collision.

   e. The test article shall smoothly redirect the vehicle. A redirection is deemed smooth if the rear of the vehicle or, in the case of a combination vehicle, the rear of the tractor or trailer does not yaw more than 5 degrees away from the railing from time of impact until the vehicle separates from the railing.

   f. The smoothness of the vehicle-railing interaction is further assessed by the effective coefficient of friction, μ:

μ	Assessment
0–0.25	Good
0.26–0.35	Fair
>0.35	Marginal

   where $\mu = (\cos\theta - V_p/V)/\sin\theta$

4

Table 2. Bridge railing performance levels and crash test criteria.
(Exerpt from 1989 AASHTO *Guide Specifications for Bridge Railings*)[3]
(continued)

g. The impact velocity of a hypothetical front-seat passenger against the vehicle interior, calculated from vehicle accelerations and 2.0-ft. longitudinal and 1.0-ft. lateral diplacements, shall be less than:

Occupant Impact Velocity–fps	
Longitudinal	Lateral
30	25

and the vehicle highest 10-ms average accelerations subsequent to the instant of hypothetical passenger impact should be less than:

Occupant Ridedown Acceleration—g's	
Longitudinal	Lateral
15	15

h. Vehicle exit angle from the barrier shall not be more than 12 degrees. Within 100 ft. plus the length of the test vehicle from the point of initial impact with the railing, the railing side of the vehicle shall move no more than 20-ft. from the line of the traffic face of the railing. The brakes shall not be applied until the vehicle has traveled at least 100-ft. plus the length of the test vehicle from the point of initial impact.

4. Values A and R are estimated values describing the test vehicle and its loading. Values of A and R are described in the figure below and calculated as follows:

Min. Load = 20.5 Kips

$$L_1 = 30'' \pm 1''$$

$$L_2 + \frac{L_3}{2} = 169'' \pm 4''$$

$$A = L_1 + \frac{W_2 L_2 + W_3(L_2 + L_3)}{W_1 + W_2 + W_3}$$

$$R = \frac{W_1 + W_2 + W_3}{W}$$

$$W = W_1 + W_2 + W_3 + W_4 + W_5$$
= total vehicle weight.

4.5' Approx. (Rear most setting.)
H_{cg} (Load) = 92" Approx.
H_{cg} (Trailer & Load) = 79" ± 1"
H_{cg} (Tractor, Trailer, & Load) = 64" ± 2"

5. Test articles that do not meet the desirable evaluation criteria shall have their performance evaluated by a designated authority that will decide whether the test article is likely to meet its intended use requirements.

---

1 mi = 1.61 km
1 kip = 4.45 kN
1 in = 25.4 mm

of resisting force provided by the railing to prevent the vehicle from rolling over the railing is at or somewhat below the center-of-gravity of the test vehicle. The 1989 guide specifications requires that the center-of-gravity of an 18,000-lb (8 172-kg) test vehicle is at 49 in (1.24 m).[3] A typical vehicle meeting the dimensional specifications weighs about 14,000 lb (6 356 kg) empty. Ballast is used to adjust the total weight and location of the center-of-gravity. The recommended design force of 56 kips (249 kN) for PL2 railings is a uniformly distributed line force 42 in (1.07 m) long located at least 29 in (740 mm) above the roadway surface.

For PL3, the test with a 50,000-lb (22 700-kg) tractor-trailer traveling at 50 mi/h (80 km/h) with an impact angle of 15 degrees is used to evaluate the strength and height of a railing. For these test conditions, the short duration (.050 s) collision force imposed on a rigid bridge railing is about 124 kips (552 kN). The required minimum height of the resultant of resisting force provided by the railing to prevent the vehicle from rolling over the railing is at or somewhat below the center-of-gravity of the test vehicle. The recommended design force of 124 kips (552 kN) for PL3 railings is a uniformly distributed line force 96 in (2.44 m) long located at least 38 in to 40 in (970 mm to 1.02 m) above the roadway surface.

Much of the information used to establish recommended values of design force was developed in two earlier FHWA research studies.[10,11] In those studies, a rigid flat-faced vertical wall was instrumented with load cells to measure transverse forces during collisions under various impact conditions. The collision forces recommended in the paragraphs above for design of railings are based on highest 0.050-s averages of measured forces. It is recommended that no factor of safety (i.e., load factor = 1.0) be used with the values of force in ultimate strength analyses of railings for specified test conditions.

In addition to providing adequate strength, a railing system must provide suitable geometrics for interaction with the vehicle. Adequate height must be provided to prevent the vehicle from rolling over the railing. Sufficient frontal area must be provided to adequately engage the vehicle and provide a smooth redirection without too much snagging and longitudinal deceleration.

For solid-faced concrete parapet type railings, these geometric features are obviously suitable. However, the shape and roughness of the face will influence performance.

For beam and post type railing systems (usually metal railings but some concrete railings), the frontal area provided must be sufficiently large to prevent the rail elements from "cutting" into the vehicle too far and allowing the vehicle to snag too much on the posts. Too much snagging on posts will impose excessive decelerations on the vehicle and will cause excessive deformation of the vehicle. However, a small amount of longitudinal deceleration of the vehicle will generally serve to reduce the exit angle of the vehicle.

General relationships that provide some guidance in establishing suitable geometrics are presented in figures 1 and 2.

6
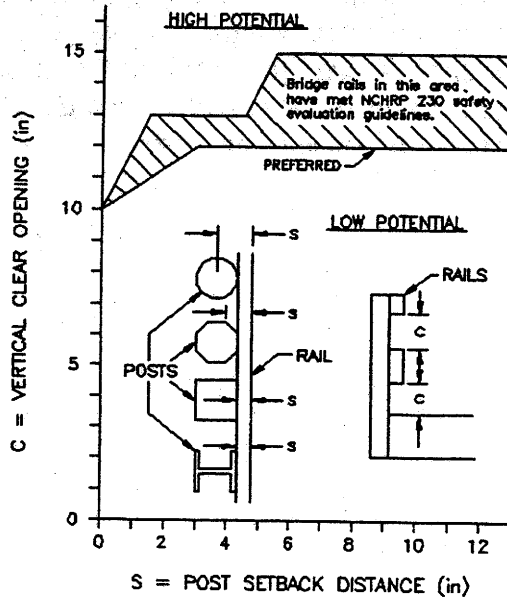
Figure 1. Relationship between vertical clear opening between rail elements and post setback distance to prevent excessive snagging of vehicle on posts.
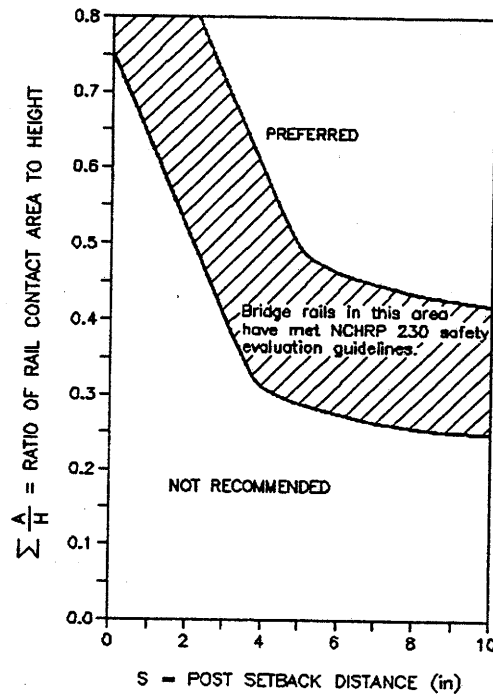
Figure 2. Relationship between the ratio of rail contact area and post setback distance to prevent excessive snagging of vehicle on posts.

If open spaces between rail elements become larger, then post setback distance needs to be increased to prevent the vehicle from snagging on the posts. However, the relationship is also influenced by the amount of frontal area provided by the rail elements. Individual vertical clear openings between rail elements should be less than 10 to 12 in (250 to 300 mm) to prevent excessive snagging of vehicles on posts.

CHAPTER 3. ANALYSIS/DESIGN PROCEDURES

Design forces for the respective performance levels are presented in chapter 2. These forces with a load factor (or factor of safety) of 1.0 are recommended for use in ultimate strength (failure mode) analysis techniques to design bridge railings. Complete detailed analyses of each bridge railing design are presented in the respective appendixes.

CONCRETE PARAPETS

A yieldline analysis procedure was used for concrete parapet bridge railings and is summarized here.[7]

The expected yieldline failure pattern for a concrete parapet is shown in figure 3. Such a failure pattern would be expected for a concentrated load or a uniformly distributed line load applied transverse to the parapet at or near the top of the parapet.

Ultimate strength of the parapet and dimensions of the yieldline pattern are functions of magnitudes of the various bending moment strengths. M_w is the moment capacity (ft-kips/ft) of the parapet for bending about a vertical axis. M_b is additional moment (in addition to M_w) capacity (ft-kips) that is provided along the top edge of the parapet. M_c is the cantilever moment (ft-kips/ft) at the base of the parapet. An increase in the beam moment, M_b, or the wall moment, M_w, serves to increase the length, L, of the yieldline pattern and, for a given ultimate load, would serve to decrease the magnitude of the cantilever moment that must be resisted by the bridge deck.

The parapet should be analyzed/designed assuming that the deck has adequate strength to support the parapet and force the failure pattern to stay within the parapet. Once this has been accomplished, values for L, M_c, and wl will be known. At a vertical section through the deck along the traffic face reinforcement of the parapet, the load wl can be assumed distributed over length equal to L. This force becomes an inplane tensile force in the deck. The deck can then be analyzed/designed to determine its adequacy for resisting the inplane force and M_c.

BEAM AND POST RAILINGS

A plastic hinge failure mechanism analysis technique for bridge railings was used for metal beam and post systems.[7] Typical failure mechanisms for such railing systems are shown in figure 4. Equations for computing ultimate load capacities for various lengths of failure mechanism are:
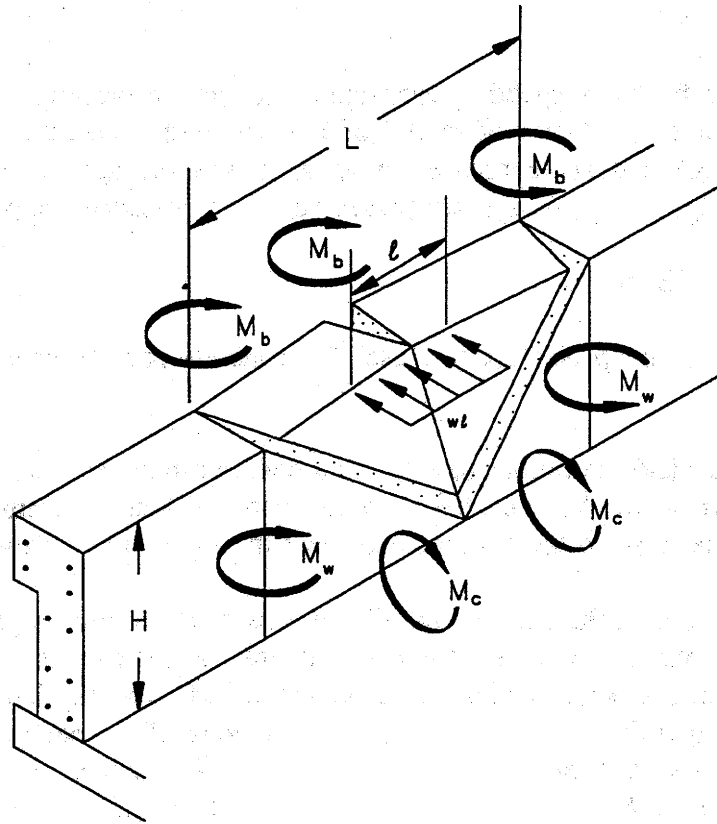
$$L = \frac{l}{2} + \sqrt{\left(\frac{l}{2}\right)^2 + 8H\left(\frac{M_b + M_w H}{M_c}\right)}$$

$$(wl)_{ult} = \frac{8M_b}{L - \dfrac{l}{2}} + \frac{8M_w H}{L - \dfrac{l}{2}} + \frac{M_c L^2}{H\left(L - \dfrac{l}{2}\right)}$$

Figure 3. Yieldline failure mechanism for concrete parapet.

PLASTIC HINGES IN RAIL ELEMENTS

1-SPAN FAILURE MECHANISM

PLASTIC HINGES IN RAIL ELEMENTS

PLASTIC HINGE IN POST

2-SPAN FAILURE MECHANISM

PLASTIC HINGES IN RAIL ELEMENTS

PLASTIC HINGES IN POSTS

3-SPAN FAILURE MECHANISM
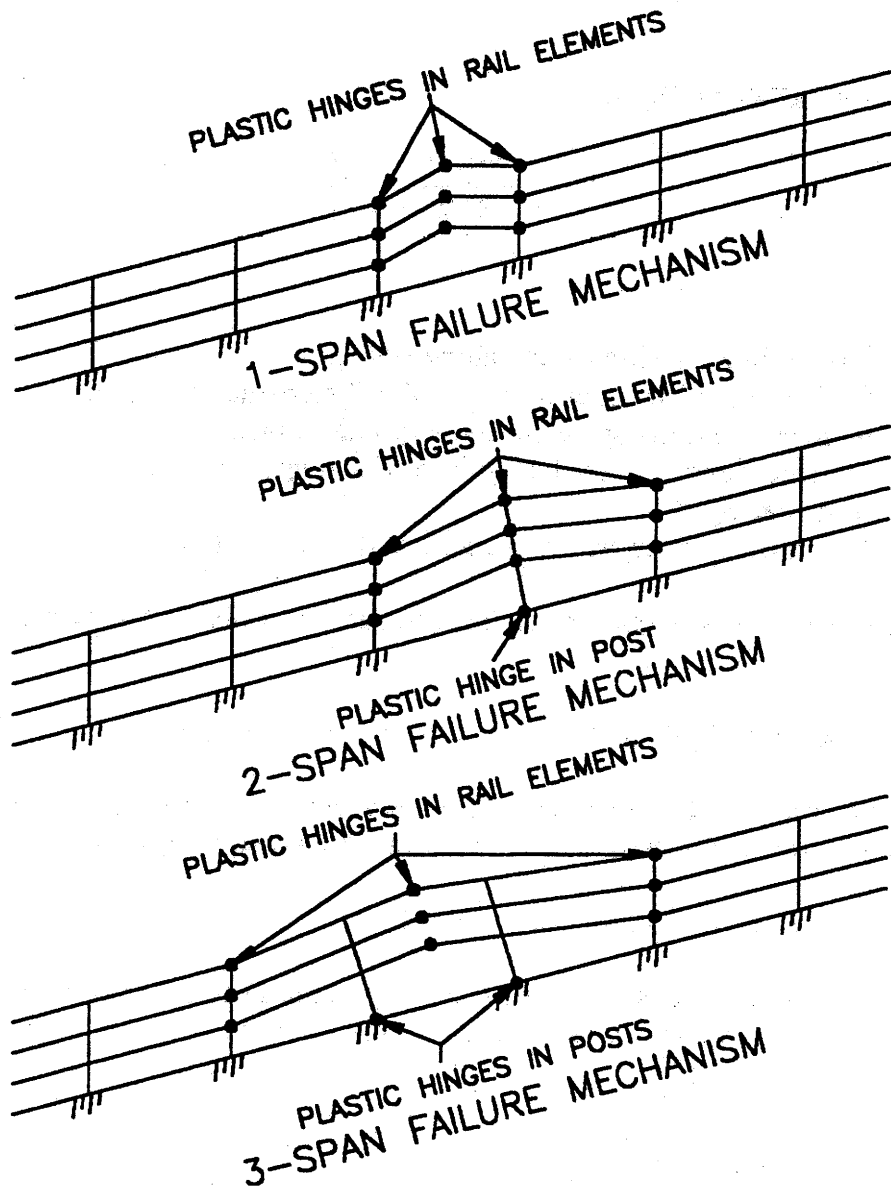
Figure 4. Possible failure mechanisms in beam-and-post railing systems.
Longer mechanisms would be similar.

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Odd number of spans

$$R = \frac{16M_p + (N - 1)(N + 1)P_pL}{2NL - L_t}$$

(1)

Even number of spans

$$R = \frac{16M_p + N^2P_pL}{2NL - L_t}$$

(2)

where:

R = total ultimate resistance of railing (kips).
M_p = total plastic moment capacity of all rail elements (in-kips).
N = number of railing spans involved in failure mechanism.
P_p = ultimate transverse load resistance of a single post (kips).
L = post spacing (ft).
L_t = length over which transverse load is distributed (ft).

It is noted that several requirements must be met for a plastic failure mechanism to occur.

1. Elastic buckling of the individual members must not occur.

2. The materials must be sufficiently ductile to form plastic hinges and allow sufficient rotation at those hinges to form a complete mechanism.

3. Connections must be adequately detailed.

4. Member cross sections must be sufficiently compact to maintain their shape without local buckling in the region of a plastic hinge.

CHAPTER 4. RAILING DESIGNS

PERFORMANCE LEVEL ONE DESIGNS

Three performance level one designs were evaluated in this study. They were:

1. Oregon Side-Mounted Railing.
2. BR27D on Sidewalk.
3. BR27D on Deck.

Oregon Side-Mounted Railing

A drawing for this railing design is shown in figure 5. A strength analysis along with more detailed drawings are presented in appendix A.

The original design for this railing was proposed by Oregon DOT. It has been used on small bridges on low volume rural roads and is typically mounted on prestressed deck planks. The W6x15 posts are mounted on the side face of exterior planks and a single thickness of 10-gauge thrie-beam is mounted to the post without a blockout. Height to the top of the rail element is 27 in (690 mm).

BR27D on Sidewalk

This railing design concept was selected by the project panel to meet a need for a railing for urban areas. Many States are currently using railing designs that are somewhat similar to BR27D in that they consist of a concrete parapet with an open metal railing on top.

BR27D was tested to PL1 both with and without the curb and sidewalk. A somewhat similar design, BR27C, was tested to PL2 both with and without the curb and sidewalk.

In the analysis and design of BR27D with curb and sidewalk, information on the influence of the curb on vehicle trajectory was needed. Some information on this subject for 3,500-lb (1 589-kg) automobiles was found in the 1977 barrier guide.[8] No data specifically for vehicles used in tests on BR27D were available. The expected influence of the 8-in (200-mm) curb on the trajectory of a Honda Civic, a pickup truck, and an 18,000-lb (8 172-kg) truck was estimated from available data. A design force of 30 kips at 35 in (890 mm) above the top surface of the sidewalk was selected for design of BR27D. A cross section of this railing design is shown in figure 6.

BR27D on Deck

Design of this railing was identical to BR27D on sidewalk. It was mounted on the deck without a curb and sidewalk. A cross section of the prototype test railing is shown in figure 7.

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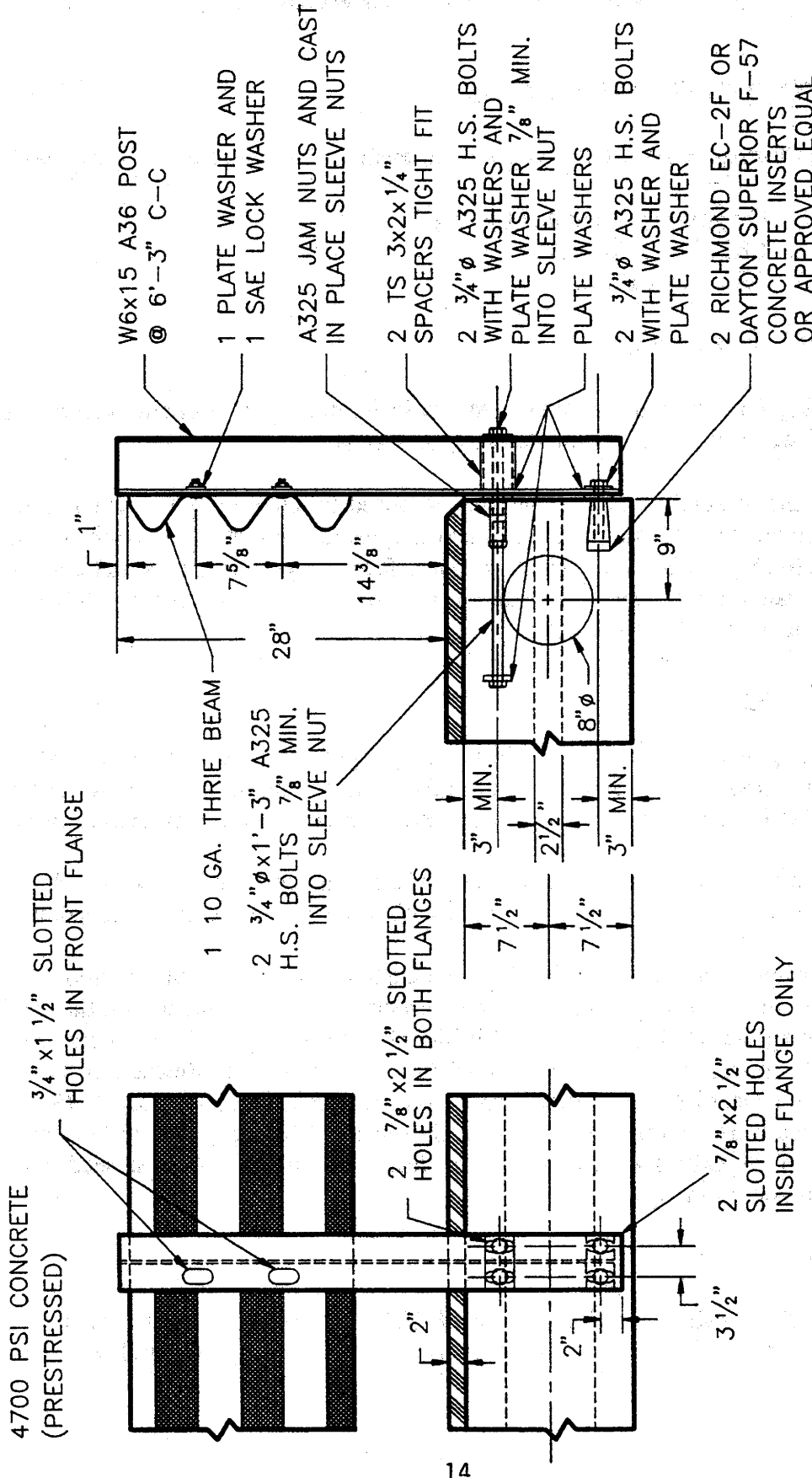
Figure 5. Details of Oregon side-mounted bridge railing.

W6x15 A36 POST @ 6'-3" C-C

1 PLATE WASHER AND 1 SAE LOCK WASHER

A325 JAM NUTS AND CAST IN PLACE SLEEVE NUTS

2 TS 3x2x1/4" SPACERS TIGHT FIT

2 3/4" ∅ A325 H.S. BOLTS WITH WASHERS AND PLATE WASHER 7/8" MIN. INTO SLEEVE NUT

PLATE WASHERS

2 3/4" ∅ A325 H.S. BOLTS WITH WASHER AND PLATE WASHER

2 RICHMOND EC-2F OR DAYTON SUPERIOR F-57 CONCRETE INSERTS OR APPROVED EQUAL

1 10 GA. THRIE BEAM

2 3/4" ∅x1'-3" A325 H.S. BOLTS 7/8" MIN. INTO SLEEVE NUT

1"

7 5/8"

14 3/8"

28"

3" MIN.

2 1/2

3" MIN.

8" ∅

9"

7 1/2"

7 1/2"

4700 PSI CONCRETE (PRESTRESSED)

3/4"x1 1/2" SLOTTED HOLES IN FRONT FLANGE

2 7/8"x2 1/2" SLOTTED HOLES IN BOTH FLANGES

2 7/8"x2 1/2" SLOTTED HOLES INSIDE FLANGE ONLY

2"

2"

3 1/2"

1 in = 25.4 mm
1 ft = 0.305 m

14

TS 4x4x³⁄₁₆" A500 GR. B
@ 6'-8" C-C

2 TS 4x3x¼" A500
GR. B RAIL ELEMENTS

½"∅x8½" LONG ROUND
HEAD A307 BOLTS (TESTED)
¾"∅ (RECOMMENDED)

⅝"∅x13" LONG
A325 BOLTS OR A321
THREADED ROD

3600 PSI CONCRETE
GRADE 60 REINFORCING STEEL

9½x10x¾" A36 PLATE

6 #4 LONGIT. BARS
#4 @ 8" C-C

#5 @ 4¾" C-C

9 #4
LONGIT.
BARS

#5 @ 9½" C-C

#5 DOWELS
@ 24" C-C IN
1"∅ HOLES

#5 DOWELS
@ 12" C-C
IN 1"∅
HOLES

12"

42"

10"

18"

2"

1½"

1"

8"

10"

1"

8"

1"

¼"

12"

2"

8"

1¼"

4"

12"

2'-5"

3'-6"

1 in = 25.4 mm
1 ft = 0.305 m

Figure 6. Cross section of BR27D bridge railing on sidewalk.

15

TS 4x4x³⁄₁₆" A500 GR. B
@ 6'-8" C-C

2 TS 4x3x¼" A500
GR. B RAIL ELEMENTS

½"∅x8½" LONG ROUND
HEAD A307 BOLTS (TESTED)
¾"∅ (RECOMMENDED)

GRADE 60 REINFORCING STEEL
3600 PSI CONCRETE

12"

⅝"∅x13" LONG
A325 BOLTS OR
A321 THREADED ROD

10"

42"

9½x10x¾" A36 PLATE

6 #4 LONGIT. BARS

18"

#4 @ 8" C-C

1"

1½"

8 #4
LONGIT.
BARS

#5 @ 4¾" C-C

2" 1"

EXISTING SLAB

1"

8"

1¼"

#5 @ 9½" C-C

10"

5'-11"
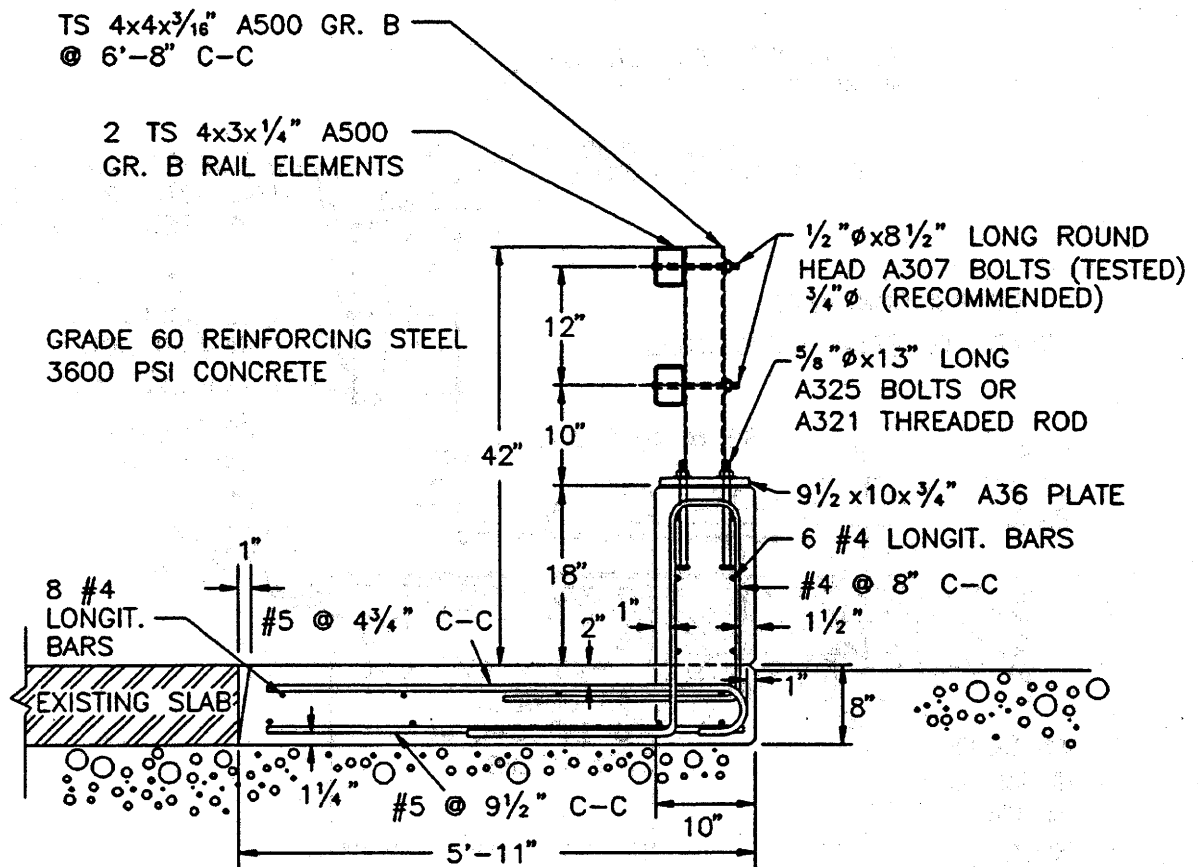
1 in = 25.4 mm
1 ft = 0.305 m

Figure 7. Cross section of BR27D bridge railing on deck.

16

PERFORMANCE LEVEL TWO DESIGNS

Seven performance level two designs were evaluated in this study. They were:

1. Illinois 2399-1 Railing.
2. 32-in (813-mm) Concrete Parapet.
3. 32-in (813-mm) New Jersey Safety Shape.
4. 32-in (813-mm) F-shape.
5. BR27C on Sidewalk.
6. BR27C on Deck.
7. Illinois Side-Mounted Railing.

Illinois 2399-1 Railing

The Illinois 2399-1 railing design is a modification of the original Illinois design (designated 2399). It was offered for use as a retrofit railing on structures which have a narrow safety walk. A cross section of the prototype test railing is shown in figure 8. The railing would be appropriate for use on new construction where it would be mounted on top of a similar curb. If no curb were present, the opening below the bottom rail element would be too large and the bending moment in the post would be increased.

32-in (813-mm) Concrete Parapet

A vertical faced concrete parapet railing was proposed by South Dakota. A cross section of the prototype design is shown in figure 9. The flat vertical face serves to smoothly redirect a vehicle with good stability in roll and pitch; however, under low-severity impact conditions, damage to the vehicle may be greater than that for a New Jersey safety shape or F-shape concrete parapet. The thickened section along the top edge of the parapet provides beam strength and enhances the longitudinal distribution of forces in the parapet and deck.

32-in (813-mm) New Jersey Safety Shape

The safety shape has been tested extensively, especially as a median barrier. Virtually all States include a safety shape in their standards both as a median barrier and as a bridge railing. It was selected for testing in this study with a pickup truck and 18,000-lb (8 172-kg) single unit truck to determine compliance with the 1989 guide specifications.[3]

The amount of steel used in the safety shape has varied significantly. Details of the prototype safety shape tested in this study are shown in figure 10. It was designed to resist forces for performance level two.

GRADE 40 REINFORCING STEEL
3600 PSI CONCRETE

TS 8x4x5/16"
A500 GR. B

W6x25 A36 @
6'-3" SPACING

TS 4x4x1/4"
A500 GR. B

1/8" FABRIC
BEARING PAD

12x13x1"
A36 PLATE

6 #4
LONGIT. BARS

#4 @
12" C-C

34"

1"

1/2"

8"

25"

4"

7"

1 1/2"

TOP OF EXISTING
OR PROPOSED
WEARING SURFACE

7"±

1 1/4"ø x17"
STEEL PIPE

2"
TYP.

17"

1"

1 #4
LONGIT. BAR

1 #5
LONGIT. BAR

3 #4
LONGIT. BARS

6"

#5 @ 7 1/2" C-C

1"ø H.S. THREADED
ANCHOR RODS

1 in = 25.4 mm
1 ft = 0.305 m

TEST INSTALLATION OVERHANG = 46"
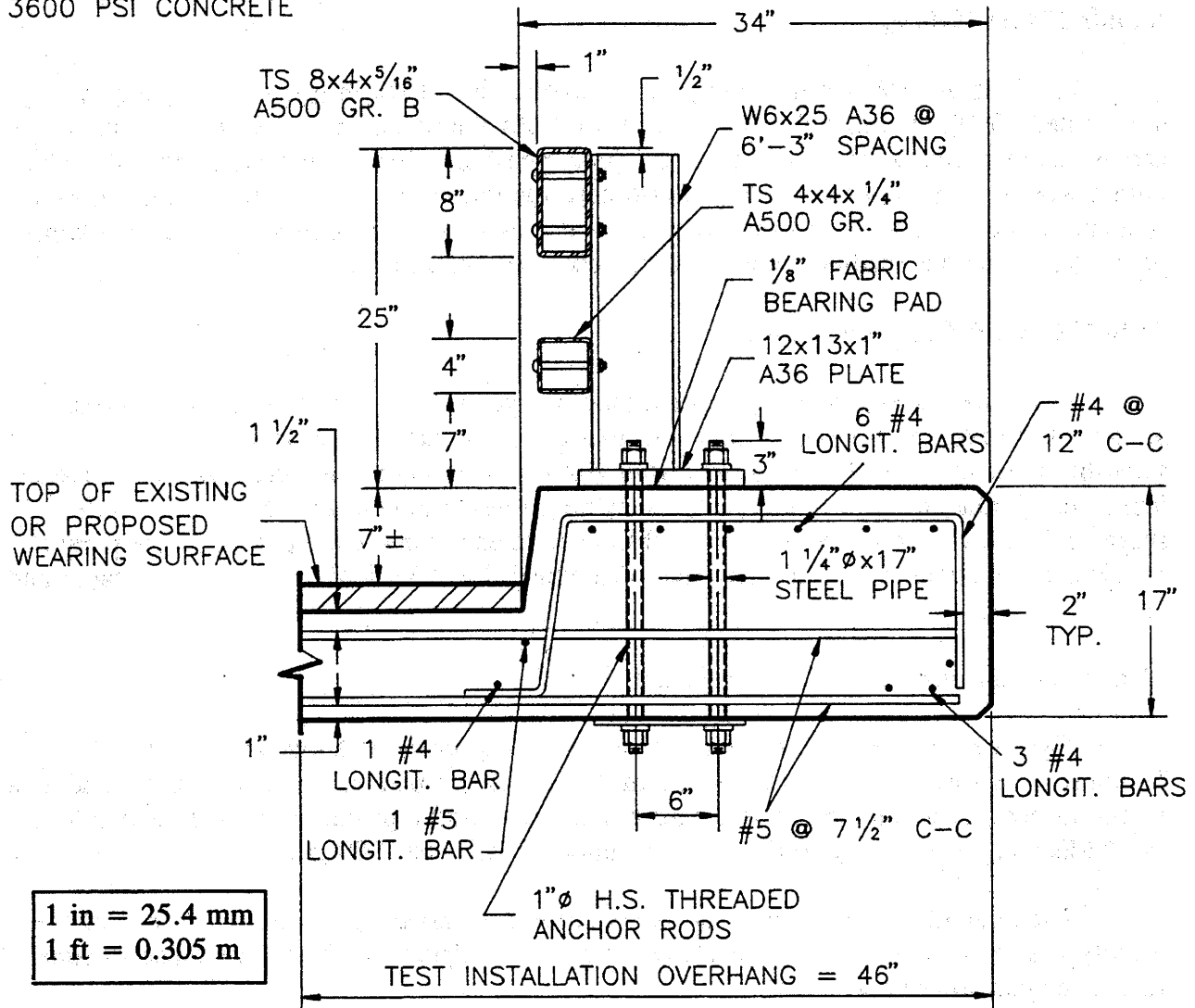
Figure 8. Cross section of Illinois 2399-1 bridge railing.

GRADE 40 REINFORCING STEEL
3600 PSI CONCRETE

10"

8"

2"

1"

1 ½"

1 ½"

32"

#4 @ 8" C-C

3 #4 LONGIT. BARS
(TOP)

8 #4 LONGIT. BARS

#5 @ 4 ¾" C-C

#4 @ 8" C-C

2"

3"

1"

8"

1 ¼"

3 #5 LONGIT. BARS
(BOTTOM)

#4 @ 9 ½" C-C

TEST INSTALLATION OVERHANG = 39"

1 in = 25.4 mm
1 ft = 0.305 m
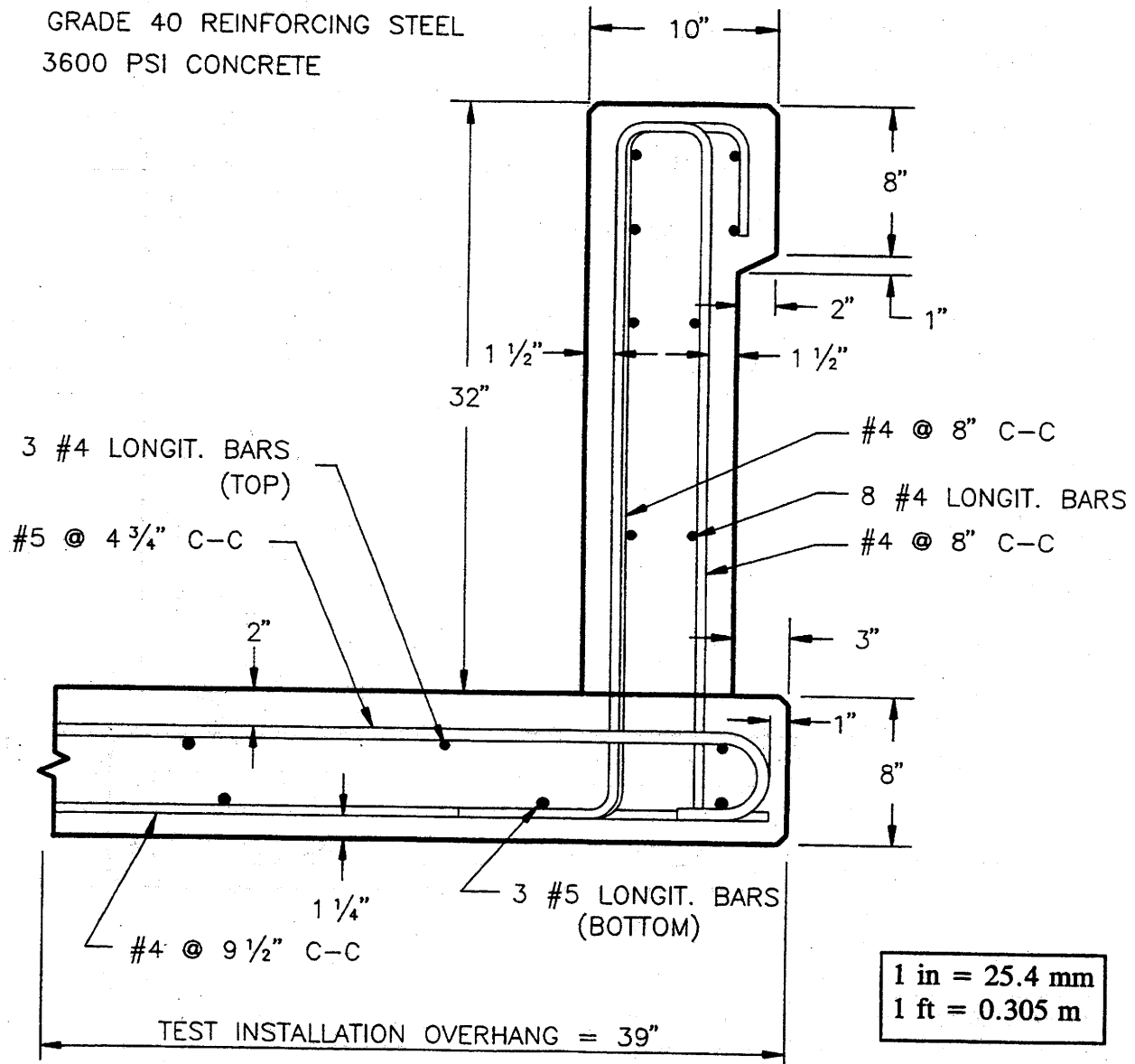
Figure 9. Cross section of 32-in (813-mm) concrete parapet.

GRADE 60 REINFORCING STEEL
3600 PSI CONCRETE

#5 @ 8" C-C

8 #4 LONGIT. BARS

#5 @ 8" C-C

#5 @ 4¾" C-C

6 #5 LONGIT. BARS

#4 @ 9½" C-C

15"

2" 6"

1½"
TYP.

32"

10"

2" 3"

8"

1"

1¼"

1 in = 25.4 mm
1 ft = 0.305 m

TEST INSTALLATION OVERHANG = 39"

Figure 10. Cross section of 32-in (813-mm) New Jersey safety shape.

20

32-in (813-mm) F-Shape

The F-shape is similar in cross section to the New Jersey Safety Shape except the geometry of lower portion of the traffic face is different. The modified lower face is intended to provide improved stability for small automobiles.

A cross section of the F-shape is shown in figure 11. It was designed to resist collision forces for performance level two.
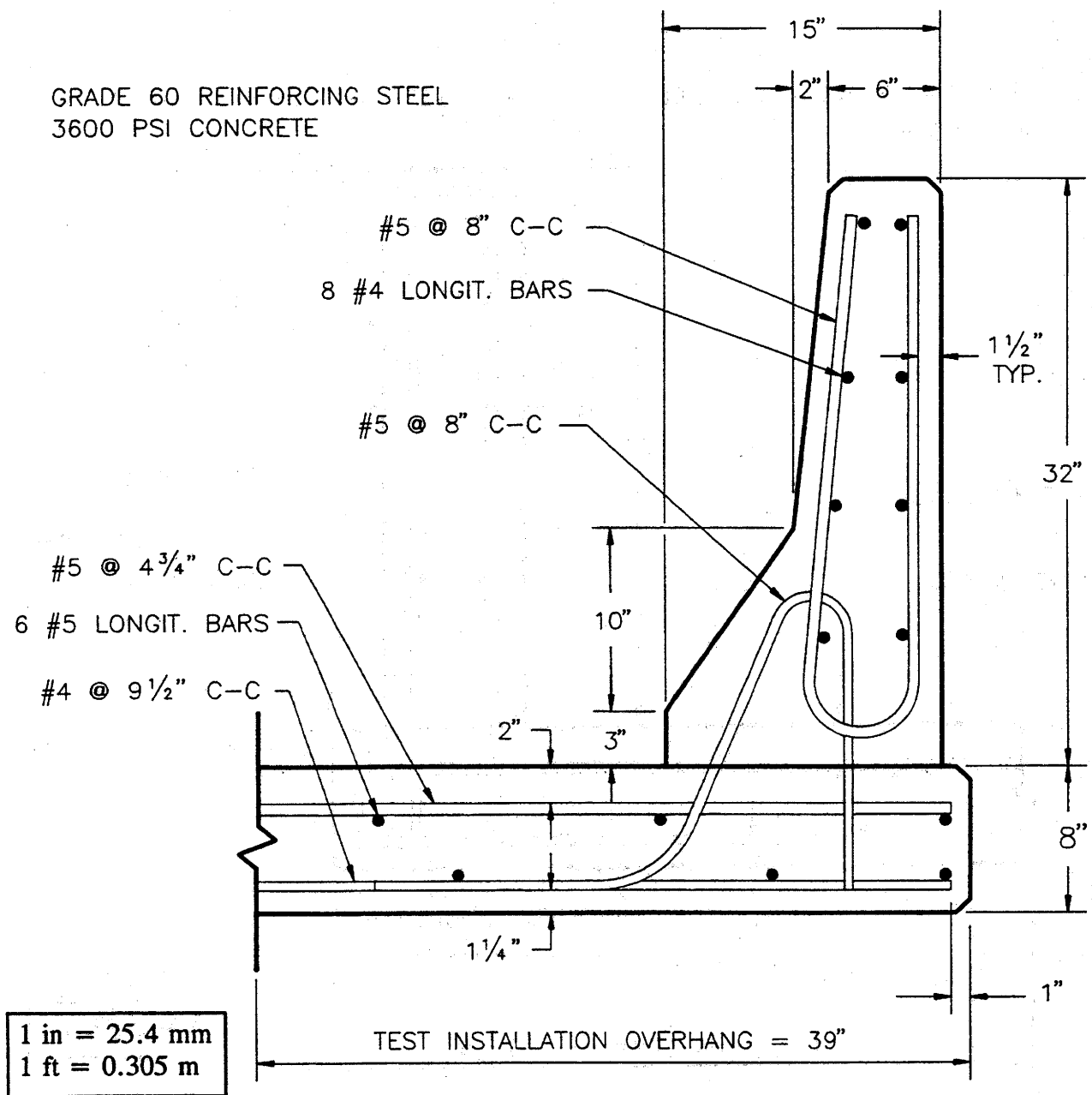
BR27C on Sidewalk

A cross section of this railing design is shown in figure 12. It was designed to meet performance level one but was tested to performance level two. Detailed design calculations are presented in appendix G.

After tests were performed on this railing, two modifications of details were made for the deck-mounted version. The rail-to-post connection bolt was changed from 1/2 to 3/4 in (13 to 19 mm) diameter and an anchorage assembly was added at the end of the anchor bolts. These modifications are recommended for both versions of the design.

BR27C on Deck

A cross section of this railing design is shown in figure 13. It is basically the same as the sidewalk mounted version but differs in two details. The rail-to-post connection bolt was changed from 1/2 to 3/4 in (13 mm to 19 mm) diameter and an anchorage assembly was installed at the bottom end of the anchor bolts. These details are also recommend for the sidewalk mounted version.

Illinois Side-Mounted Railing

A cross section of this railing is shown in figure 14. The railing is composed of two A500 grade B steel tubular rails mounted on AASHTO M183 wide-flange steel posts. The W6x25 posts are mounted on the side of a prestressed concrete slab and are 4 ft 1-1/4 in (1.25 m) long, spaced at 6 ft 3 in (1.9 m). The top rail is an 8-in by 4-in by 5/16-in (203-mm by 102-mm by 8-mm) tubular rail, and the bottom rail is a 6-in by 4-in by 1/4-in (152-mm by 102-mm by 6-mm) tubular rail. This railing system has a height of 32 in (813-mm) above the bituminous surface. The center of the top rail is 28 in (710 mm) above the surface.

GRADE 40 REINFORCING STEEL
3600 PSI CONCRETE

14³⁄₄"

4⁷⁄₈"   7¹⁄₂"

12"

1¹⁄₂"

32"

1¹⁄₂"

8 #4 LONGIT. BARS

1¹⁄₂"

#5 @ 4³⁄₄" C-C

#5 @ 8" C-C

#5 @ 8" C-C

7"

3"

1¹⁄₂"

2"

8"

1¹⁄₄"

6 #5 LONGIT. BARS

1"

#4 @ 9¹⁄₂" C-C

TEST INSTALLATION OVERHANG = 39"
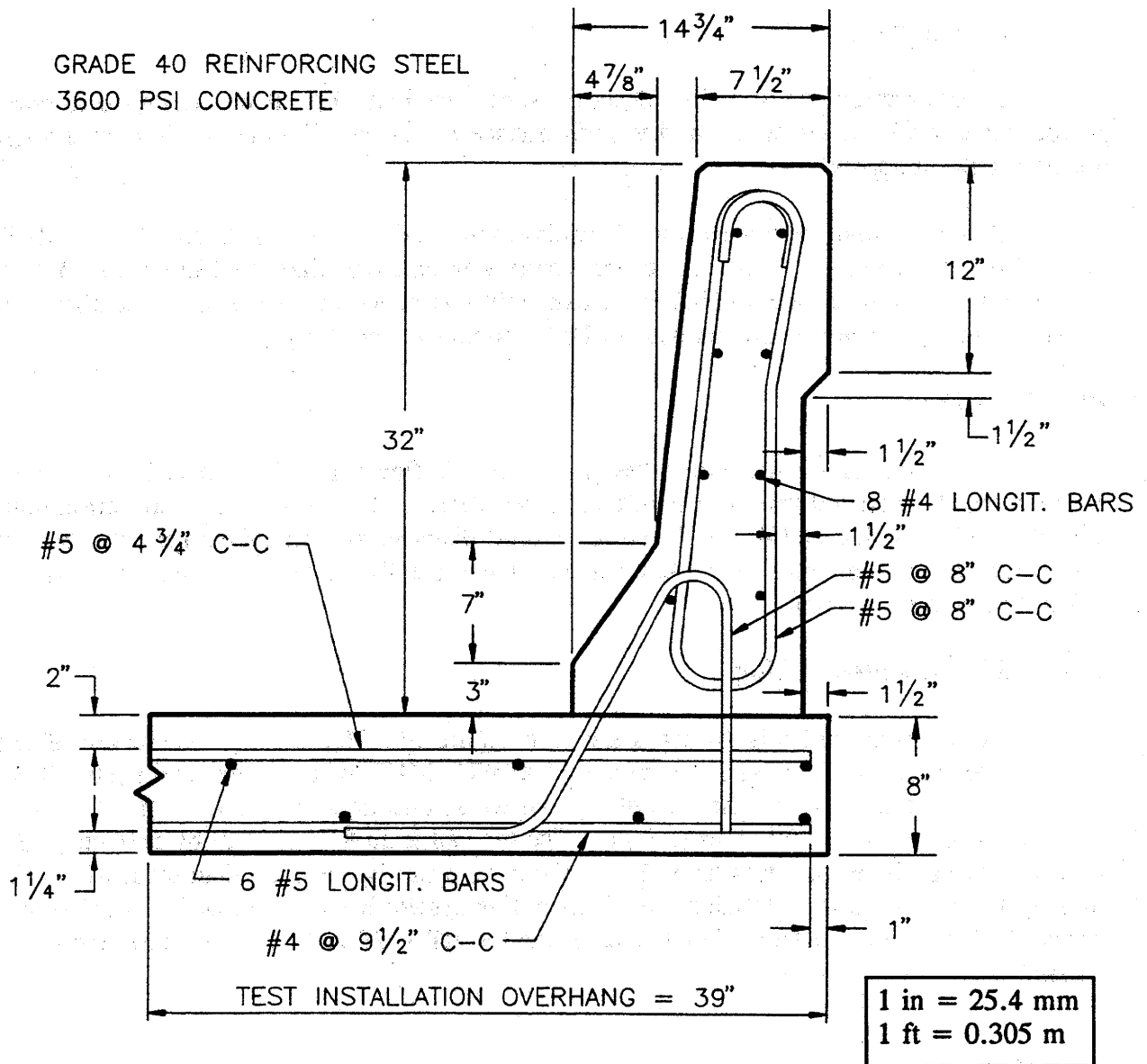
1 in = 25.4 mm
1 ft = 0.305 m

Figure 11. Cross section of 32-in (813-mm) F-shape bridge railing.

22

TS 4x3x¼" A500 GR. B

½"ø x8½" LONG ROUND HEAD A307 BOLTS (TESTED) ¾"ø (RECOMMENDED)

TS 4x4x³⁄₁₆" A500 GR. B @ 6'-8" C-C

⅝"ø x13" LONG A325 BOLTS OR A321 THREADED ROD EMBEDDED 10" IN CONCRETE PARAPET

GRADE 60 REINFORCING STEEL 3600 PSI CONCRETE

16"

42"

8½ x9½ x¾" A36 PLATE

1½"

2"

24"

6 #4 LONGIT. BARS

#4 @ 8" C-C

#5 @ 4¾" C-C

9 #4 LONGIT. BARS

1"

2"

¼"

12"

1"

8"

WALL 12" THICK

FOOTING

8"

1½"

#5 @ 9½" C-C

10"

10"

4"—12"

#5 DOWELS @ 12" C-C IN 1"ø HOLES

#5 DOWELS @ 24" C-C IN 1"ø HOLES

12"

2'-5"

3'-6"

1'-6"

1 in = 25.4 mm
1 ft = 0.305 m

Figure 12. Cross section of BR27C bridge railing on sidewalk.

GRADE 60 REINFORCING STEEL
3600 PSI CONCRETE

TS 4x3x ¼" A500 GR. B

¾"ø x8 ½" LONG
ROUND HEAD A307 BOLTS

TS 4x4x³⁄₁₆" A500 GR. B
@ 6'–8" C–C

⅝"ø x13" LONG A325
BOLTS OR A321 THREADED
ROD EMBEDDED 10"
IN CONCRETE PARAPET

8 ½ x9 ½ x ¾" A36 PLATE

2 2x7⅜ x ⅜"
A36 FLAT BARS

6 #4 LONGIT. BARS

#4 @ 8" C–C

16"

42"

24"

1 ½"

1 ½"

1"

8"

#5 @ 4 ¾" C–C

4 #4 LONGIT.
BARS (TOP)

2"

1 #4
LONGIT. BAR

1 ¼"

3 #5 LONGIT. BARS
(BOTTOM)

10"

#4 @ 8 ½" C–C

TEST INSTALLATION
OVERHANG = 39"

1 in = 25.4 mm
1 ft = 0.305 m

Figure 13. Cross section of BR27C bridge railing on deck.

24

8"x4"x5/16"
Steel Tubing
A500 Gr. B.

1/2"

3/4"∅ ASTM A307 Round Head Bolts
with Lock Washer and Flat Washer (typ.)

AASHTO M 183 W6x25x4'-1¼"
at 6'-3" spacing

6"x4"x1/4"
Steel Tubing
A500 Gr. B.

2-3/4"∅ ASTM A307 Round Head Bolts
with Lock Washer and Flat Washer

13/16"∅ holes
in angles

Center Line of 13/16" x 5 1/2"
Slotted Hole

1 3/4"

4 1/4"

6"

2-1"∅ x 7 3/4" AASHTO M 164
Anchor Bolts with flat washer
and lock washer

L6x4x3/4

2-5/8"∅ x 5 3/4" AASHTO M 164
Anchor Bolts with flat and lock washer

TS 6" x 3" x 1/4" x 3 1/2" Long

Bituminous
Surface

2 1/2"

12"

2"

3"

10"

4"

1/2" x 7" x 6" Plate

TS 6" X 4" X 1/4" X 4" long

8"

6"

6"

2"

4"

3"

1 in = 25.4 mm
1 ft = 0.305 m

Figure 14. Cross section of Illinois side-mounted bridge railing.

25

PERFORMANCE LEVEL THREE DESIGNS

Two performance level three designs were evaluated in this study. They were:

1. 42-in (1.07-m) Concrete Parapet.
2. 42-in (1.07-m) F-shape.

42-in (1.07-m) Concrete Parapet

A cross section of this railing is shown in figure 15. The thickened section at the top edge of the parapet serves to strengthen the parapet and enhance longitudinal distribution of forces within the parapet and the deck. The deck extension on the field side of the parapet was considered necessary to provide adequate anchorage of the reinforcement in the top of the deck.

42-in (1.07-m) F-Shape

A cross section of the prototype 42-in (1.07-m) F-shape is shown in figure 16. The slope at the bottom traffic face of the parapet serves to minimize vehicle damage (for automobiles) at low angles of impact by causing the tire to ride up on the parapet and redirect itself back to the pavement. The thickened section at the top acts as a continuous beam and enhances longitudinal distribution of forces in the parapet and deck. It also influences the appearance of the field side face of the parapet. The deck extension beyond the field side face of the parapet was deemed necessary to provide adequate anchorage of the top reinforcement in the deck.
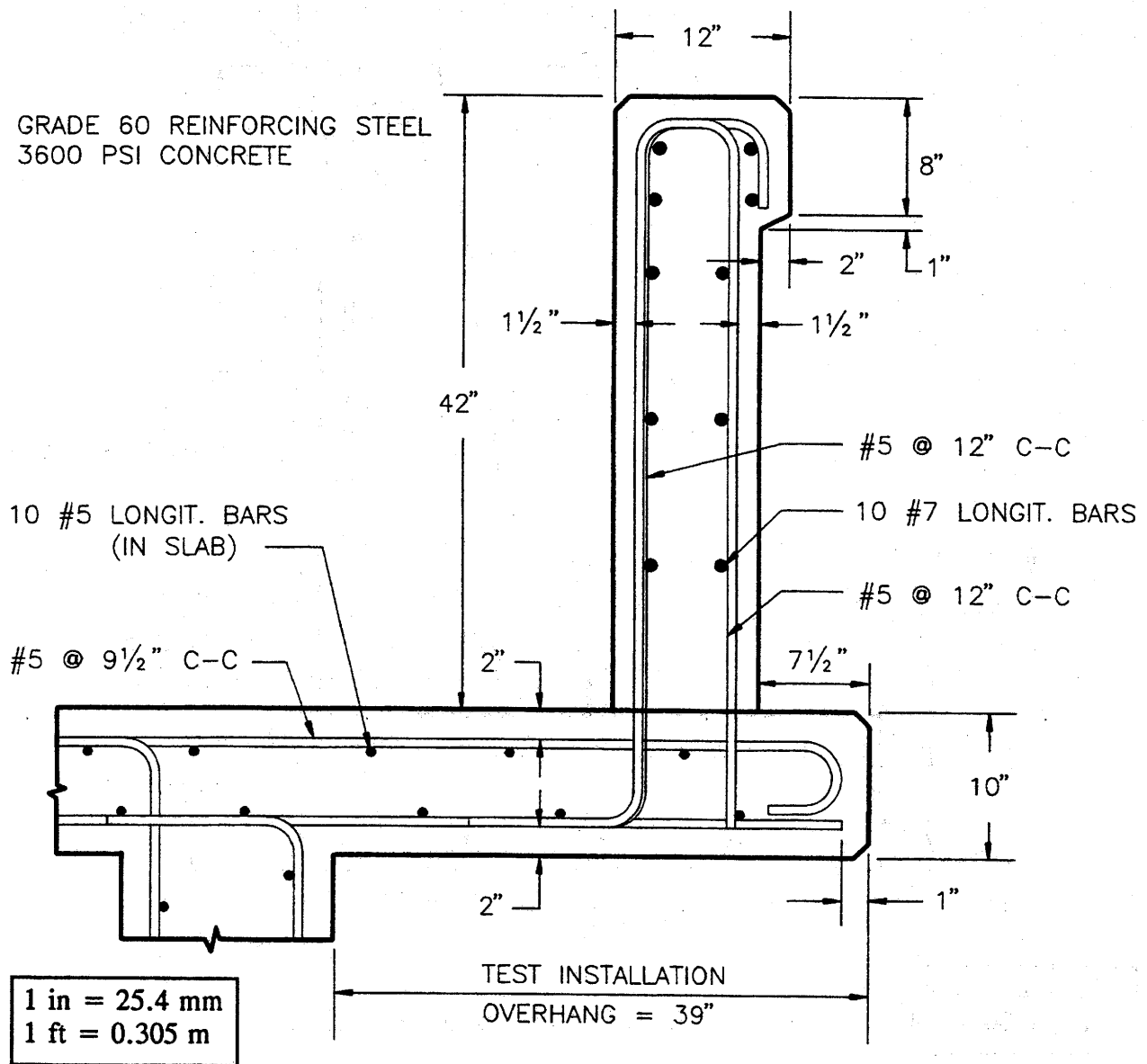
GRADE 60 REINFORCING STEEL
3600 PSI CONCRETE

12"

8"

2"   1"

1½"   1½"

42"

#5 @ 12" C-C

10 #5 LONGIT. BARS
(IN SLAB)

10 #7 LONGIT. BARS

#5 @ 12" C-C

#5 @ 9½" C-C

2"

7½"

10"

2"

1"

TEST INSTALLATION
OVERHANG = 39"

1 in = 25.4 mm
1 ft = 0.305 m

Figure 15. Cross section of 42-in (1.07-m) concrete parapet.

27

GRADE 40 REINFORCING STEEL
3600 PSI CONCRETE

17¼"

4⅞"   9"

4 #7
LONGIT. BARS

12"

42"

1½"

1½"

4 #8
LONGIT. BARS

#5 @ 4¾" C-C

3 #4 LONGIT. BARS
(TOP)

7"

1½"

#5 @ 8" C-C

#5 @ 8" C-C

2"

3"

3"

10"

1¼"

3 #5 LONGIT. BARS (BOTTOM)

#4 @ 9½" C-C

1"

1 in = 25.4 mm
1 ft = 0.305 m

TEST INSTALLATION OVERHANG = 39"
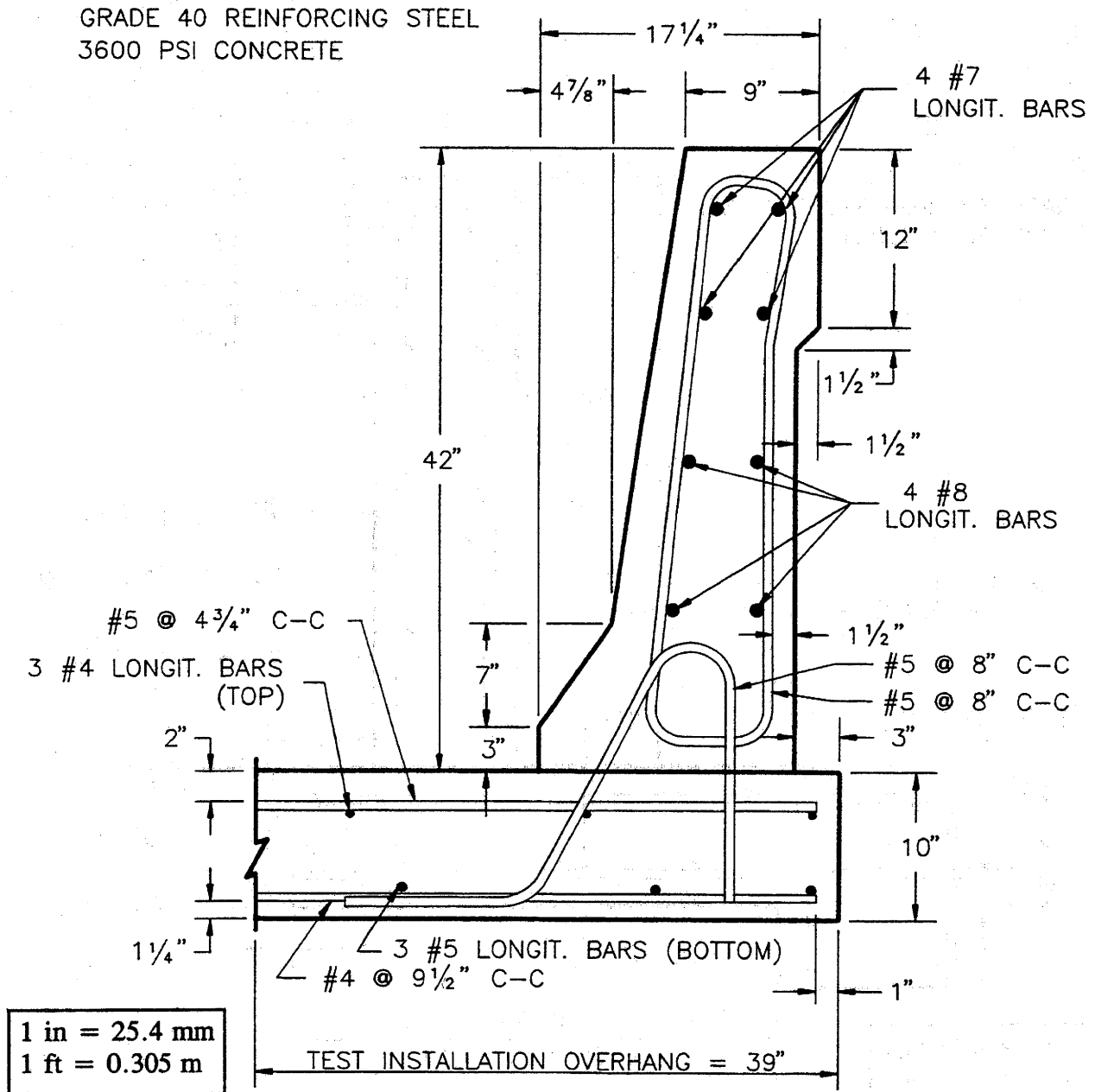
Figure 16. Cross section of 42-in (1.07 m) F-shape.

CHAPTER 5. TRANSITION DESIGNS

Two transition designs were developed and tested in this study. One was a performance level one transition. The original design came from Oregon and it is intended for use with the Oregon side-mounted bridge railing. The other is a 32-in (813-mm) high thrie-beam transition for performance level two. It was tested on the 32-in (813-mm) concrete parapet bridge railing but it is also intended for use with other performance level two bridge railings where it can be suitably attached to the bridge railing.

PERFORMANCE LEVEL ONE DESIGN

Oregon Thrie-Beam Transition

Drawings for the Oregon thrie-beam transition are shown in figure 17. The bridge rail element is a 10-gauge thrie-beam which terminates at the end of the bridge. A 12-gauge W-beam connects at this point and continues straight through the transition. An additional 10-gauge thrie-beam element is connected behind the W-beam at the end of the bridge and extends straight for 6 ft-3 in (1.9 m), then curves to the field side on an 11 1/2-ft (3.5-m) radius for a distance of 6 ft-3 in (1.9 m). Timber posts 8 in by 8 in by 6-ft-0 in (203 mm by by 203 mm by 1.8 m) and blockouts spaced at 3 ft-1 1/2 in (1.0 m) are used in the transition.

Because transition rails are flexible and most bridge rails are either rigid or semi-rigid, guardrail-to-bridge rail transitions must be designed to prevent impacting vehicles from deflecting the guardrail sufficiently to allow vehicle snagging on the end of the rigid bridge railing. Curving the thrie-beam away from the traffic face creates an area that provides smooth transition from lower stiffness of the W-beam guardrail to higher stiffness of the thrie-beam bridge rail. Consequently, an impacting vehicle is prevented from snagging along the transition and sustaining high levels of damage or injury. In addition, curving the thrie-beam prevents the vehicle from snagging on the end of the thrie-beam itself.
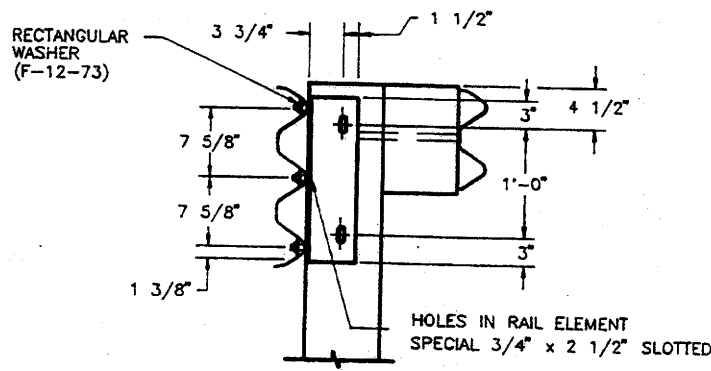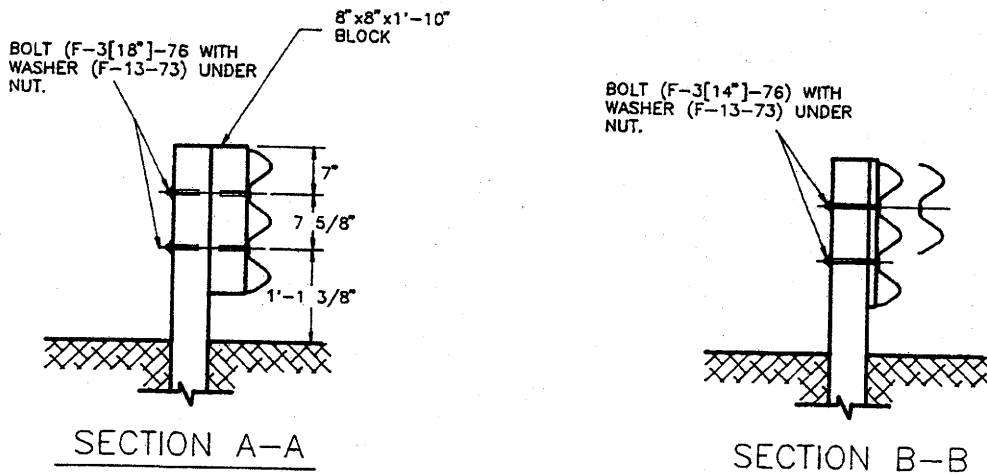
PERFORMANCE LEVEL TWO DESIGN

32-in (813-mm) Thrie-Beam Transition

Drawings for the 32-in (813-mm) thrie-beam transition are presented in figure 18. The prototype transition was installed on the 32-in (813-mm) concrete parapet for testing. A terminal connector was used at the transition-to-parapet connection. In the first two tests (automobile and pickup truck), a standard AASHTO terminal connector was used.[9] The terminal connector was lapped on the traffic face with the two layers of thrie-beam being sandwiched between the terminal connector and the parapet. In a connection such as this
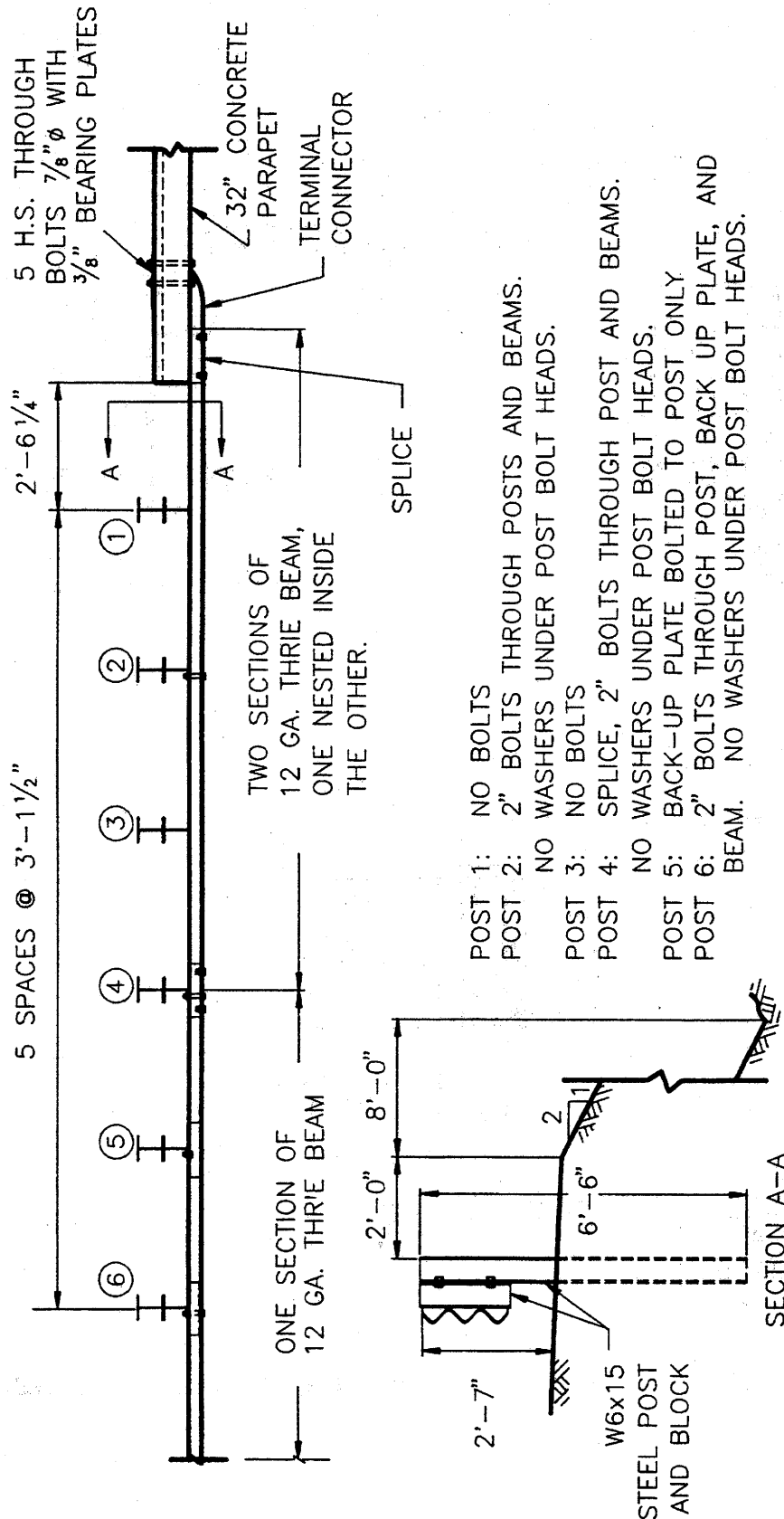
Figure 17. Details of Oregon thrie-beam transition.

GUARD RAIL TRANSITION 12'-6"
1-10GA. THRIE BEAM (SEE DETAIL C, SHEET 2 OF 2)
AND 1-12GA. W-BEAM (STRAIGHT)
4 SPACES @ 3'-1 1/2"

8"x8"x8'-0"
TIMBER POST
& BLOCK (TYP.)

6'-3" TYP.

1 3/4"

1 3/4"

W 6x15

EXISTING STRUCTURE

END OF PRESTRESSED SLAB

1-10GA.
THRIE BEAM

1 - 10 GA. THRIE BEAM
(RE-6J[4@6'-3=25'-0" CLASS A,TYPE 2]-76

SPLICE BOLTS [F-3J[1 1/4"]-76)

PLAN

11'-5" RADIUS

1-12GA. W-BEAM

(RE-3[8@3'-1 1/2"=25'-0" CLASS A, TYPE II]-73)
1 - 12 GA. W-BEAM

1 - 10 GA. CURVED THRIE-BEAM

POST NUMBER

ELEVATION

W-BEAM AND THRIE-BEAM SPLICE

EXISTING STRUCTURE

1 in = 25.4 mm
1 ft = 0.305 m

30

BOLT (F-3[18"]-76 WITH
WASHER (F-13-73) UNDER
NUT.

8"x8"x1'-10"
BLOCK

7"

7 5/8"

1'-1 3/8"

SECTION A-A

BOLT (F-3[14"]-76) WITH
WASHER (F-13-73) UNDER
NUT.

SECTION B-B

RECTANGULAR
WASHER
(F-12-73)

3 3/4"

1 1/2"

3"

4 1/2"

7 5/8"

1'-0"

7 5/8"

3"

1 3/8"

HOLES IN RAIL ELEMENT
SPECIAL 3/4" x 2 1/2" SLOTTED

SECTION C-C

| 1 in = 25.4 mm |
| 1 ft = 0.305 m |

Figure 17. Details of Oregon thrie-beam transition. (continued)

31

5 H.S. THROUGH BOLTS 7/8" φ WITH 3/8" BEARING PLATES

32" CONCRETE PARAPET

TERMINAL CONNECTOR

SPLICE

2'-6 1/4"

5 SPACES @ 3'-1 1/2"

A

A

① ② ③ ④ ⑤ ⑥

TWO SECTIONS OF 12 GA. THRIE BEAM, ONE NESTED INSIDE THE OTHER.

ONE SECTION OF 12 GA. THR'IE BEAM

POST 1:   NO BOLTS
POST 2:   2" BOLTS THROUGH POSTS AND BEAMS.
          NO WASHERS UNDER POST BOLT HEADS.
POST 3:   NO BOLTS
POST 4:   SPLICE, 2" BOLTS THROUGH POST AND BEAMS.
          NO WASHERS UNDER POST BOLT HEADS.
POST 5:   BACK-UP PLATE BOLTED TO POST ONLY
POST 6:   2" BOLTS THROUGH POST, BACK UP PLATE, AND
          BEAM. NO WASHERS UNDER POST BOLT HEADS.

8'-0"

2'-0"

6'-6"

2

1

SECTION A-A

2'-7"

W6x15 STEEL POST AND BLOCK

1 in = 25.4 mm
1 ft = 0.305 m

Figure 18.   Cross section of 32-in (813-mm) thrie-beam transition.

32

with three layers of rail element, splice bolts cannot be inserted in the holes unless the holes in at least one layer of material are enlarged.

For the repeat of the pickup truck test (test 7069-21) and the 18,000-lb (8 172-kg) truck test (test 7069-29), a modified terminal connector was used. In test 21, the connector thickness was 12 gauge; and in test 29, it was 10 gauge. It has slanted, slotted holes to facilitate assembly of the splice as shown in figure 19. It was sandwiched between the two layers of thrie-beam rail element.
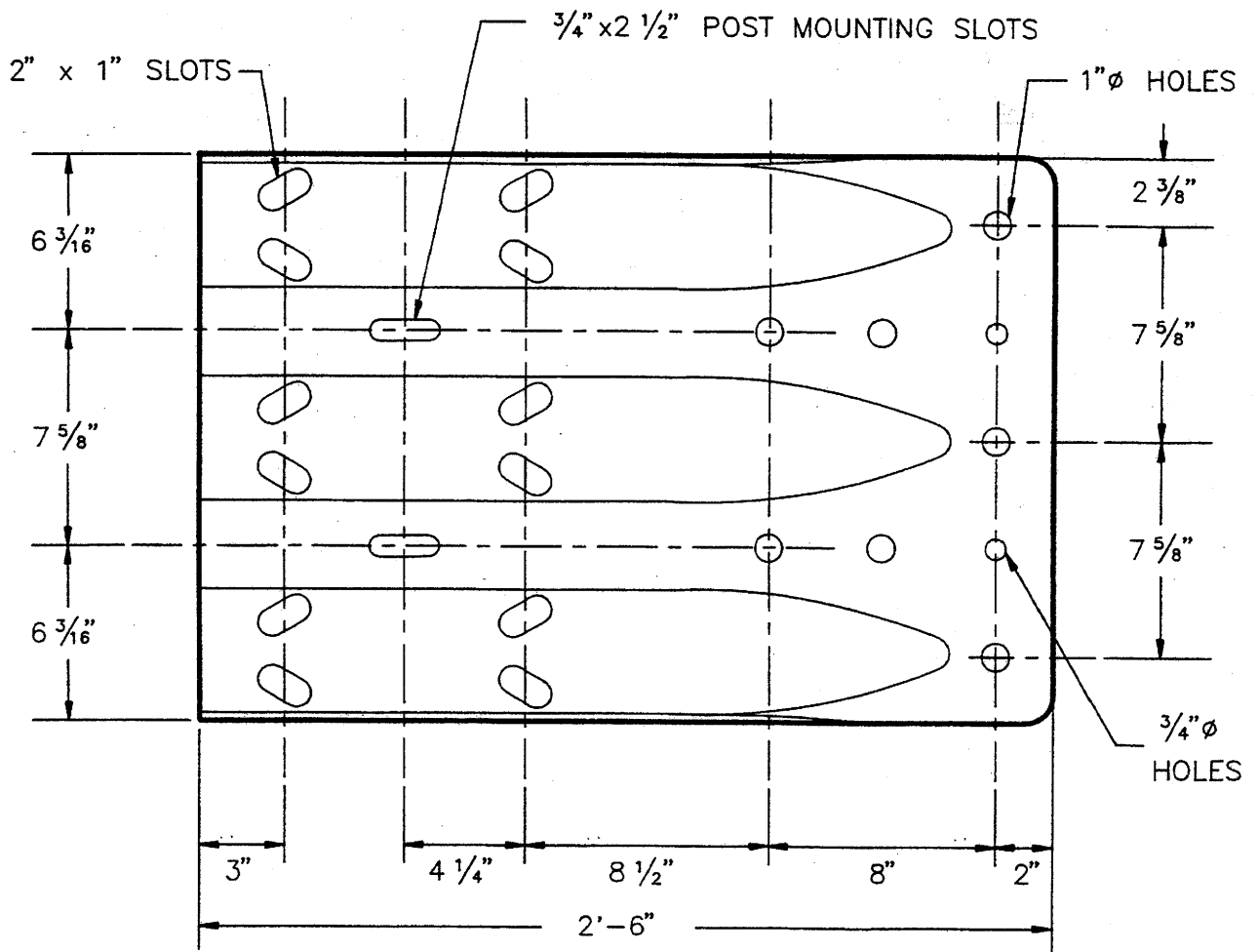
Figure 19. Modified terminal connector.

34

CHAPTER 6. SUMMARY OF CRASH TEST RESULTS

A total of 37 full-scale crash tests were performed on the railing and transition designs evaluated in this study. Results of these tests are summarized in this chapter and details of the tests are given in appendixes A through L.

PERFORMANCE LEVEL ONE RAILINGS

Performance level one railings evaluated in this study were: Oregon side-mounted thrie-beam railing and bridge railing BR27D mounted both on a sidewalk and on the deck. Tests performed on these railings are listed in table 2. In all tests, the performance obtained is judged acceptable.

The Oregon side-mounted railing is a rather uncomplicated design that uses mostly standard hardware items. It has adequate strength and height for performance level one and, under the more severe impact, exhibits plastic deformation that serves to limit accelerations imposed on the vehicle. Plastic deformation was confined to metal railing components and no damage was caused to the deck.

A transition for this railing has been tested and evaluated and results are presented near the end of this chapter.

Railing design BR27D was tested to performance level one under two situations. First, it was tested when mounted on a 5-ft (1.5-m) wide sidewalk with an 8-in (203 mm) high curb at the face of the sidewalk. It was also tested when mounted flush on the deck. Acceptable results were obtained in both series of tests. For the most part, the railing functioned as a "rigid" railing with only a small amount of permanent deformation in the metal railing in the more severe tests.

Table 2. Summary of full-scale crash tests performed on performance level one railings.

RAILING DESIGN	TEST NO.	TEST DATE	ACTUAL CONDITIONS	DESIGN CONDITIONS	COMMENTS
OREGON SIDE-MOUNTED	7069-17	5/10/89	1,970 lb|52.2 mi/h|19.7 deg (894 kg|84.0 km/h|19.7 deg)	1,800 lb|50 mi/h|20 deg (817 kg|80.5 km/h|20 deg)	Acceptable
	7069-18	5/12/89	5,737 lb|46.1 mi/h|20.9 deg 2 605 kg|74.2 km/h|20.9 deg)	5,400 lb|45 mi/h|20 deg 2 452 kg|72.4 km/h|20 deg	Acceptable
BR27D ON SIDEWALK	7069-22	3/24/92	1,967 lb|51.7 mi/h|20.8 deg (893 kg|83.2 km/h|20.8 deg)	1,800 lb|50 mi/h|20 deg (817 kg|80.5 km/h|20 deg)	Acceptable
	7069-23	3/26/92	5,565 lb|45.3 mi/h|20.2 deg (2 527 kg|72.9 km/h|20.2 deg)	5,400 lb|45 mi/h|20 deg (2 452 kg|72.4 km/h|20 deg)	Acceptable
BR27D ON DECK	7069-30	5/19/92	1,970 lb|51.2 mi/h|20.5 deg (894 kg|82.4 km/h|20.5 deg)	1,800 lb|50 mi/h|20 deg 817 kg|80.5 km/h|20 deg	Acceptable
	7069-31	5/21/92	5,400 lb|45.6 mi/h|18.8 deg (2 527 kg|73.4 km/h|18.8 deg)	5,400 lb|45 mi/h|20 deg 2 452 kg|72.4 km/h|20 deg	Acceptable

Oregon Side-Mounted Railing

Test number 7069-17

Vehicle:	1980 Honda Civic
Test Inertia Weight:	1,800 lb (817 kg)
Gross Static Weight:	1,970 lb (894 kg)
Impact Speed:	52.2 mi/h (84.0 km/h)
Impact Angle:	19.7 deg

The vehicle impacted the bridge railing approximately 20.6 ft (6.3 m) from the upstream end. It began to redirect at 0.042 s after impact. By 0.175 s the vehicle was traveling parallel to the bridge railing at a speed of 44.0 mi/h (70.8 km/hr). Shortly thereafter, the rear of the vehicle impacted the bridge railing. The vehicle lost contact with the bridge railing at 0.261 s traveling at 42.7 mi/h (68.7 km/h) and 7.1 degrees. It was in contact with the railing for 9.3 ft (2.8 m). The brakes were applied 82 ft (2.5 m) from impact and the vehicle yawed clockwise. The vehicle subsequently came to rest 172 ft (5.2 m) downstream and 30 ft (9 m) to the field side of the point of impact.

The railing received moderated damage (figure 20). Maximum lateral deflection was 0.5 in (13 mm) at the top of post 5. At post 4, the top anchor bolts connecting the post to the bridge deck showed structural distress. One bolt was pulled from the anchor insert in the concrete. Post 5 was bent outward about 0.5 in (13 mm) at the top and the top anchor bolts showed structural distress. One of the bolts in this post was also pulled from the anchor insert.

After-test examination of anchor bolts in all the posts show that the bolts had been cut off during construction and, in some, only three or four threads were engaged in the anchor insert. The plans called for a minimum of 7/8 in (22 mm) thread engagement. Evidently, concrete had flowed into the anchors during fabrication of the prestressed deck slabs and the anchor bolts had been cut off to prevent them from bottoming out. This was not detected during the construction inspection process. Prior to the next test, concrete was removed from all anchor inserts and new full-length anchor bolts were installed.

The vehicle sustained damage to the right side (figure 21). Maximum crush at the right front corner at bumper height was 9.0 in (229 mm). The strut and constant velocity joint on the impact side were damaged. The right front wheel was canted inward at the bottom and pushed back into the fender well. The right side window was broken out by the dummy's head. Also, damage was done to the front bumper, hood, grill, radiator and fan, right front quarter panel, and right door.

The railing contained the vehicle with minimal lateral movement of the bridge railing. There was no intrusion into the occupant compartment and no deformation of the compartment. The vehicle remained upright and relatively stable during the collision. The bridge railing smoothly redirected the vehicle and the effective coefficient of friction was
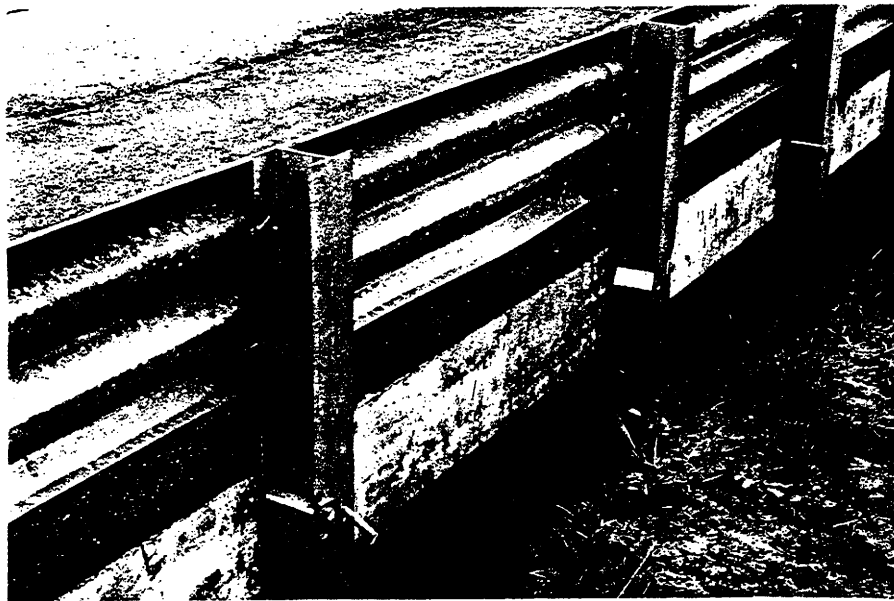
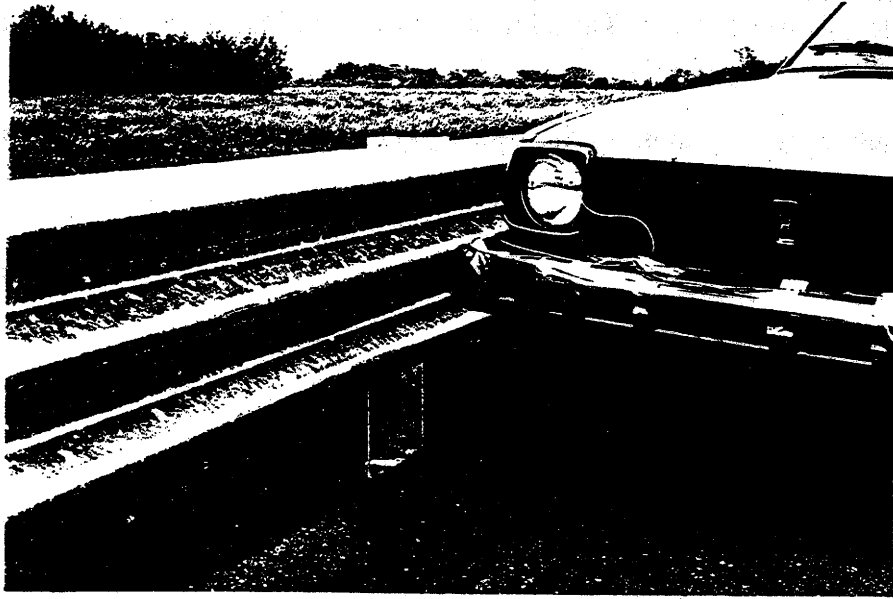Figure 20. Damage to railing system in test 7069-17.
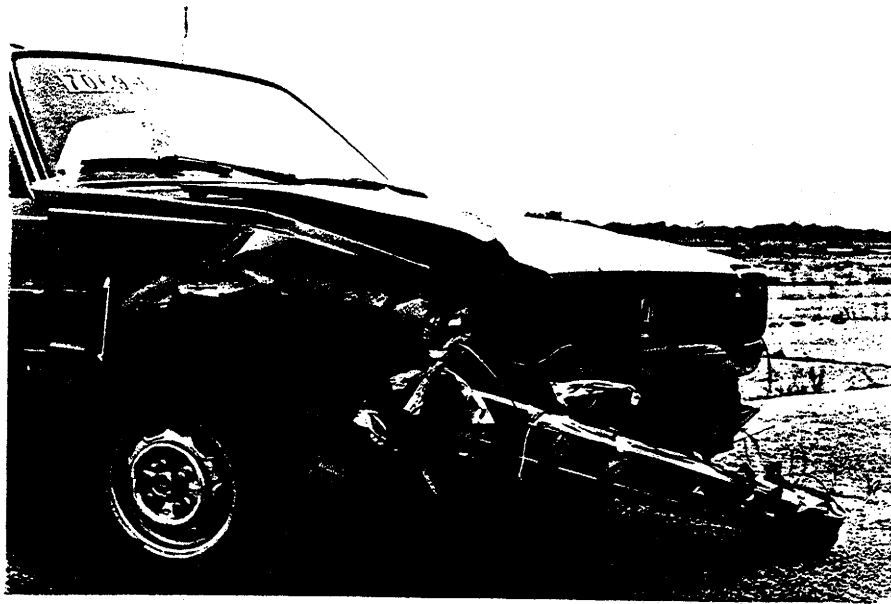
Figure 21. Vehicle and railing for test 7069-17.

considered fair. The occupant risk factors were within the limits recommended in the 1989 AASHTO guide specifications.[3] The vehicle trajectory at loss of contact indicates minimum intrusion into adjacent traffic lanes.

Performance of the railing in this test is judged acceptable, as indicated in figure 22 and table 3.

0.000 s 0.074 s 0.148 s 0.261 s
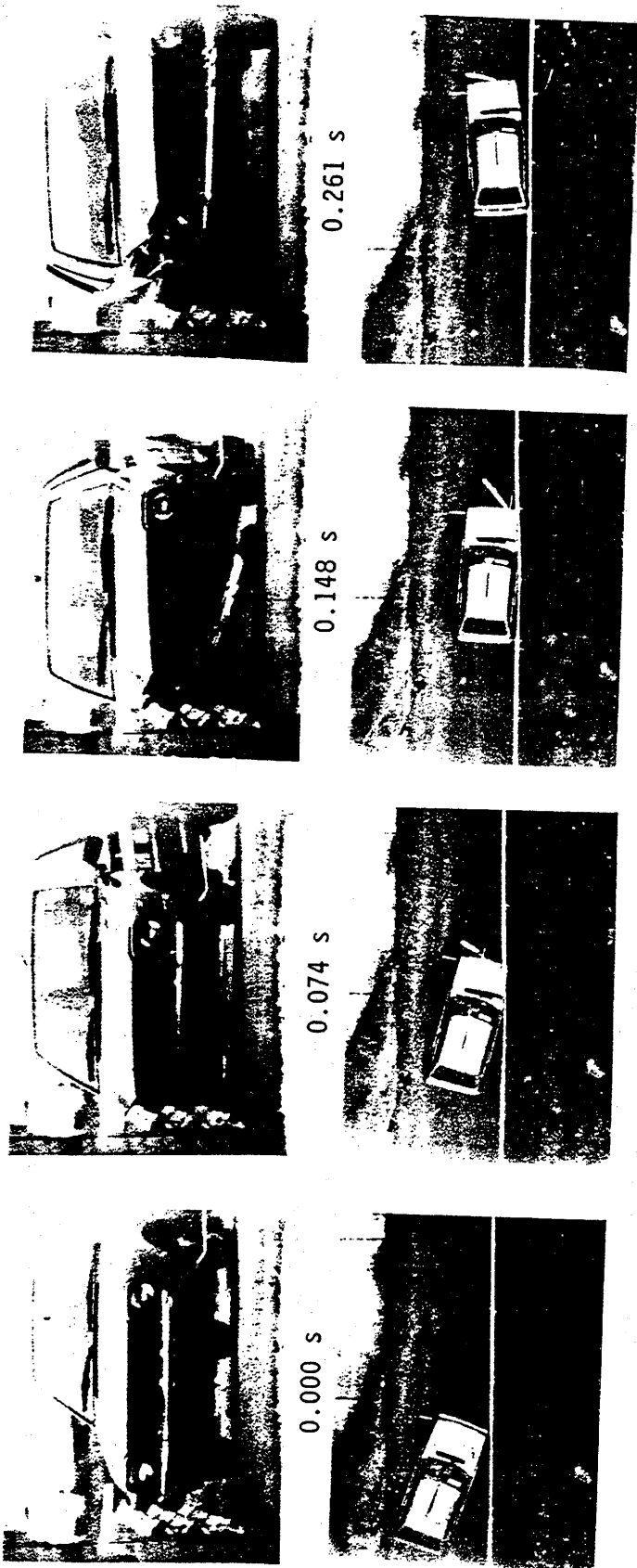
Test No.	. .	7069-17
Date	. .	05/10/89
Test Installation	. .	Oregon Side-Mounted Bridge Railing
Installation Length . . .	. .	85 ft (16 m)
Test Vehicle	. .	1980 Honda Civic
Vehicle Weight		
Test Inertia	. .	1,800 lb (817 kg)
Gross Static	. .	1,970 lb (894 kg)
Vehicle Damage Classification		
TAD	. .	01FR4 & 01RFQ3
CDC	. .	01FREK2 & 01RFEW3
Maximum Vehicle Crush .	. .	9.0 in (229 mm)

Impact Speed.	. .	52.2 mi/h (84.0 km/h)
Impact Angle.	. .	19.7 deg
Speed at Parallel . .	. .	44.0 mi/h (70.8 km/h)
Exit Speed	. .	42.7 mi/h (68.7 km/h)
Exit Trajectory . . .	. .	7.1 deg
Vehicle Accelerations		
(Max. 0.050-sec Avg)		
Longitudinal. . .	. .	-5.2 g
Lateral	. .	8.4 g
Occupant Impact Velocity		
Longitudinal. . .	. .	18.8 ft/s (5.7 m/s)
Lateral	. .	18.9 ft/s (5.8 m/s)
Occupant Ridedown Accelerations		
Longitudinal. . .	. .	-1.8 g
Lateral	. .	4.5 g
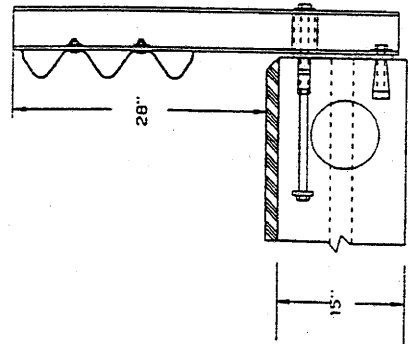
Figure 22. Summary of results for test 7069-17.

1 in = 25.4 mm

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Table 3. Evaluation of crash test no. 7069-17.
{Oregon Side-Mounted Bridge Railing [1,800 lb (817 kg)|52.2 mi/h (84.0 km/h)|19.7 degrees]}

CRITERIA	TEST RESULTS	PASS/FAIL*
A. Must contain vehicle	Vehicle was contained	Pass
B. Debris shall not penetrate passenger compartment	No debris penetrated passenger compartment	Pass
C. Passenger compartment must have essentially no deformation	Acceptable deformation	Pass
D. Vehicle must remain upright	Vehicle did remain upright	Pass
E. Must smoothly redirect the vehicle	Vehicle was smoothly redirected	Pass
F. Effective coefficient of friction μ Assessment 0 - .25 Good .26 - .35 Fair > .35 Marginal	μ Assessment .29 Fair	Pass
G. Shall be less than Occupant Impact Velocity - ft/s (m/s) Longitudinal Lateral 30 (9.2) 25 (7.6) Occupant Ridedown Accelerations - g's Longitudinal Lateral 15 15	Occupant Impact Velocity - ft/s (m/s) Longitudinal Lateral 18.8 (5.7) 18.9 (5.8) Occupant Ridedown Accelerations - g's Longitudinal Lateral -1.8 4.5	Pass
H. Exit angle shall be less than 12 degrees	Exit angle was 7.1 degrees	Pass

* A, B, C, D and G are required. E, F, and H are desired. (See table 1)

42

Vehicle:	1982 Chevrolet Pickup
Test Inertia Weight:	5,400 lb (2 452 kg)
Gross Static Weight:	5,737 lb (2 605 kg)
Impact Speed:	46.1 mi/h (74.2 km/h)
Impact Angle:	20.9 deg

The vehicle impacted the bridge railing approximately 41.3 ft (12.6 m) from the upstream end. It began to redirect at 0.054 s. By 0.234 s the vehicle was traveling parallel to the railing at a speed of 38.2 mi/h (61.5 m), and at approximately the same time the rear of the vehicle impacted the railing. The vehicle lost contact with the bridge railing at 0.458 s traveling at 35.9 mi/h (57.8 km/h) and 10.9 degrees. It was in contact with the railing for 16.3 ft (5.0 m). The brakes were applied 38 ft (11.6 m) from impact and the vehicle yawed clockwise. The vehicle subsequently came to rest 150 ft (46 m) down and 10 ft (3 m) to the field side of the point of impact.

The railing received moderate damage (figure 23). At post 8 the upper deck bolts connecting the post to the bridge deck were bent and the post was bent back 1.5 in (38 mm) at the bridge deck surface. Post 9 was bent 2.5 in (64 mm), the upper deck bolt on the right side was bent, and the upper deck bolt on the left side pulled through the outer flange. Post 10 was slightly twisted. Maximum lateral deflection was 13.0 in (330 mm) at the top of the thrie-beam between posts 8 and 9.

The vehicle sustained damage to the right side as shown in figure 24. Maximum crush at the right front corner at bumper height was 6.5 in (165 mm). The right front tire deflated, and the rim was bent. The right side window was broken out by the dummy's head. Also, damage was done to the front bumper, hood, grill, right front and rear quarter panels, and right door.

The railing contained the vehicle with minimal lateral movement of the bridge railing. There was no intrusion into the occupant compartment and no deformation of the compartment. The vehicle remained upright and relatively stable during the collision. The railing smoothly redirected the vehicle and the effective coefficient of friction was considered fair. The occupant risk factors were within the limits recommended in the 1989 AASHTO guide specifications.[3] The vehicle trajectory at loss of contact indicates minimum intrusion into adjacent traffic lanes.

Performance of the railing in this test is judged acceptable, as indicated in figure 25 and table 4.
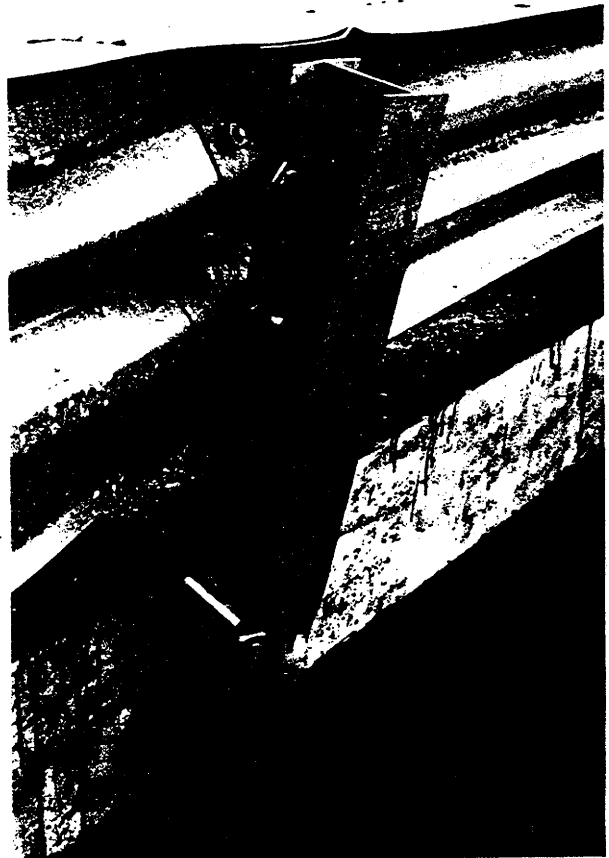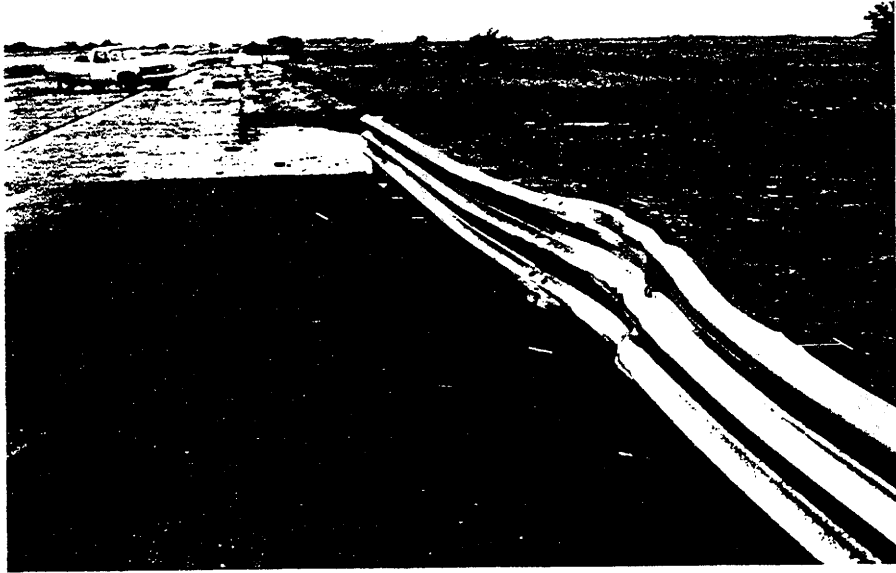
Figure 23. Damage to railing in test 7069-18.
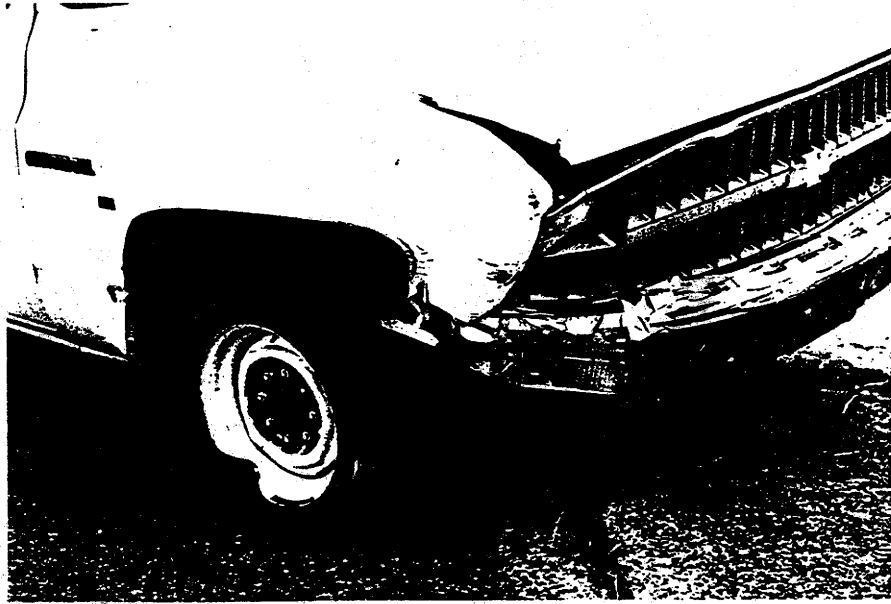
Figure 24. Damage to vehicle in test 7069-18.

45

| 0.000 s | 0.123 s | 0.246 s | 0.369 s |
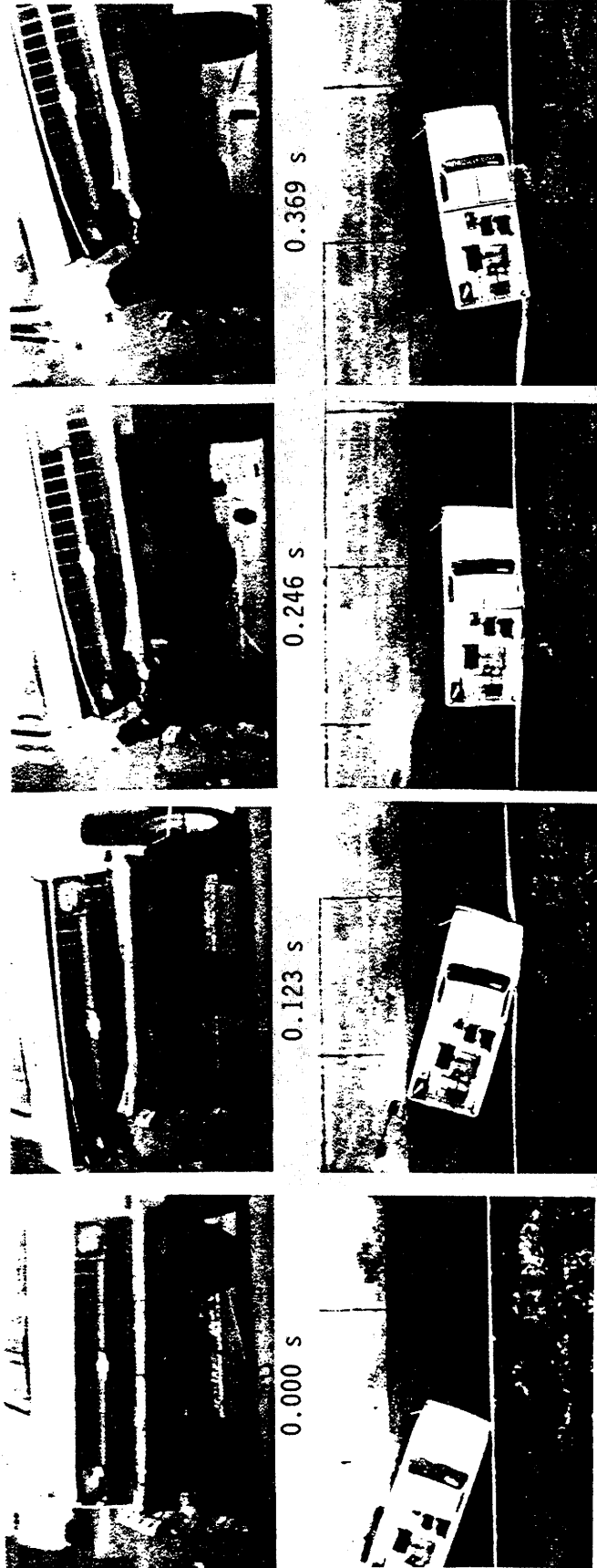
Test No. 7069-18
Date 05/12/89

Test Installation . . . . . Oregon Side-Mounted
                              Bridge Railing
Installation Length . . . 85 ft (26 m)

Test Vehicle . . . . 1982 Chevrolet
                              Custom Deluxe Pickup
Vehicle Weight
  Test Inertia . . . . . . 5,400 lb (2 452 kg)
  Gross Static . . . . . 5,737 lb (2 605 kg)
Vehicle Damage Classification
  TAD . . . . 01RF2 & 01RFQ3
  CDC . . . . 01FREK2 & 01RFEW2
Maximum Vehicle Crush . 6.5 in (165 mm)

Impact Speed. . . . . . . 46.1 mi/h (74.2 km/h)
Impact Angle. . . . . . . 20.9 deg
Speed at Parallel . . 38.2 mi/h (61.5 km/h)
Exit Speed . . . . 35.9 mi/h (57.8 km/h)
Exit Trajectory . . . . 10.9 deg
Vehicle Accelerations
  (Max. 0.050-sec Avg)
  Longitudinal. . . . . -3.8 g
  Lateral . . . . 6.7 g
Occupant Impact Velocity
  Longitudinal. . . . . 17.1 ft/s (5.2 m/s)
  Lateral . . . . . . 11.7 ft/s (3.6 m/s)
Occupant Ridedown Accelerations
  Longitudinal. . . . . -3.6 g
  Lateral . . . . . . 8.8 g
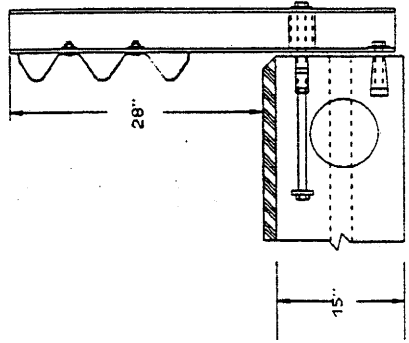
Figure 25.   Summary of results for test 7069-18.

1 in = 25.4 mm

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Table 4. Evaluation of crash test no. 7069-18.
{Oregon Side-Mounted Bridge Railing [5,400 lb (2 452 kg)|46.1 mi/h (74.2 km/h)|20.9 degrees]}

	CRITERIA	TEST RESULTS	PASS/FAIL*
A.	Must contain vehicle	Vehicle was contained	Pass
B.	Debris shall not penetrate passenger compartment	No debris penetrated passenger compartment	Pass
C.	Passenger compartment must have essentially no deformation	Acceptable deformation	Pass
D.	Vehicle must remain upright	Vehicle did remain upright	Pass
E.	Must smoothly redirect the vehicle	Vehicle was smoothly redirected	Pass
F.	Effective coefficient of friction $\underline{\mu}$ Assessment 0 - .25 Good .26 - .35 Fair > .35 Marginal	$\underline{\mu}$ Assessment .29 Fair	Pass
G.	Shall be less than Occupant Impact Velocity - ft/s (m/s) Longitudinal Lateral 30 (9.2) 25 (7.6) Occupant Ridedown Accelerations - g's Longitudinal Lateral 15 15	Occupant Impact Velocity - ft/s (m/s) Longitudinal Lateral 17.1 (5.2) 11.7 (3.6) Occupant Ridedown Accelerations - g's Longitudinal Lateral -3.6 8.8	Pass
H.	Exit angle shall be less than 12 degrees	Exit angle was 10.9 degrees	Pass

* A, B, C, and D are required. E, F, G and H are desired. (See table 1)

47

BR27D on Sidewalk

Vehicle:	1983 Honda Civic
Test Inertia Weight:	1,800 lb (817 kg)
Gross Static Weight:	1,967 lb (893 kg)
Impact Speed:	51.7 mi/h (83.2 km/h)
Impact Angle:	20.8 deg

Upon impact with the curb, the left front tire folded under the vehicle, and at 0.109 s after impact the left rear wheel impacted the curb. As the left rear wheel climbed the curb, the right front wheel lost contact with the roadway. At 0.217 s the right front wheel contacted the curb and the left side of the vehicle was airborne. When the right front wheel reached the top the curb, the vehicle was totally airborne and remained as such as it impacted the concrete parapet at 0.261 s. The vehicle impacted the parapet at post 5 traveling at a speed of 46.6 mi/h (75.0 km/h) and at an angle of 13.4 degrees. As the vehicle continued forward, the bumper protruded between the upper and lower metal railing elements. At 0.332 s the vehicle began to redirect. The right rear wheel struck the curb at 0.414 s as the vehicle was still airborne. By 0.510 s the vehicle was traveling parallel to the bridge railing at a speed of 41.0 mi/h (66.0 km/h), and at the same time the rear of the vehicle impacted the parapet. The vehicle lost contact with the parapet at 0.610 s traveling at 40.8 mi/h (65.6 km/h) and 6.1 degrees. The vehicle contacted the roadway again as it reached posts 7 and 8 and the brakes were applied. The vehicle left the installation and subsequently came to rest 165 ft (50 m) from the point of impact.

As can be seen in figure 26, the bridge railing system received minimal damage. There was no measurable permanent deformation to the railing elements and only cosmetic damage to the concrete parapet. There were tire marks on the concrete parapet and on the face of the lower metal railing element in the area of impact, and also on the lower part of post 6. The vehicle was in contact with the bridge railing for 11.5 ft (3.5 m). Length of contact with the concrete parapet was 7.0 ft (2.1 m).

The vehicle sustained damage to the left side as shown in figure 26. Maximum crush at the left front corner at bumper height was 6.0 in (152 mm). The left front strut was damaged and the left front wheel was canted inward at the bottom and pushed back reducing the wheelbase on the driver side by 2 in (51 mm). Also, damage was done to the front bumper, hood, left headlight, left front quarter panel, left rear quarter panel, left front and rear tires and rims, and right front tire.

The railing contained the vehicle with no lateral movement of the metal railing element of the bridge railing system. There was no intrusion of railing components into the occupant compartment and no debris to present undue hazard to other traffic. The integrity of the occupant compartment was maintained with no intrusion and no deformation. The vehicle remained upright and relatively stable during the collision. The bridge railing
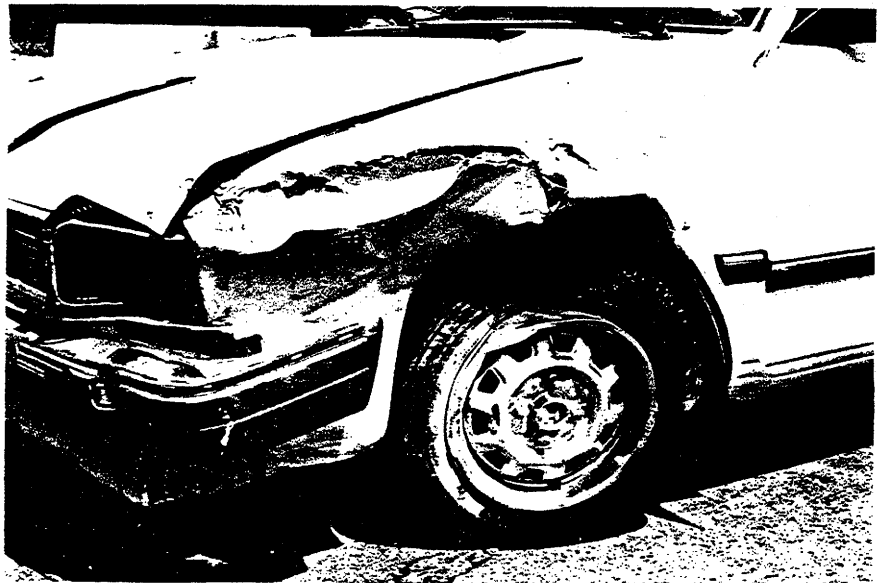
Figure 26. Vehicle and railing for test 7069-22.

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smoothly redirected the vehicle. The effective coefficient of friction was considered marginal. The occupant impact velocities and the occupant ridedown accelerations were within the limits. Vehicle trajectory at loss of contact indicated minimum intrusion into adjacent traffic lanes.

Performance of the railing in this test is judged acceptable, as indicated in figure 27 and table 5.

51

	0.000 s	0.161 s	0.321 s	0.482 s

Test No. 7069-22
Date 03/24/92

Test Installation . . . . BR27D Bridge Railing
                              on sidewalk
Installation Length . . . 100 ft (30 m)

Test Vehicle . . . . 1983 Honda Civic
Vehicle Weight
  Test Inertia . . . . . . 1,800 lb (817 kg)
  Gross Static . . . . . . 1,967 lb (893 kg)
Vehicle Damage Classification
  TAD 11LFQ3
  CDC . . . . 11FLEK2 & 11LFES2
Maximum Vehicle Crush . 6.0 in (152 mm)
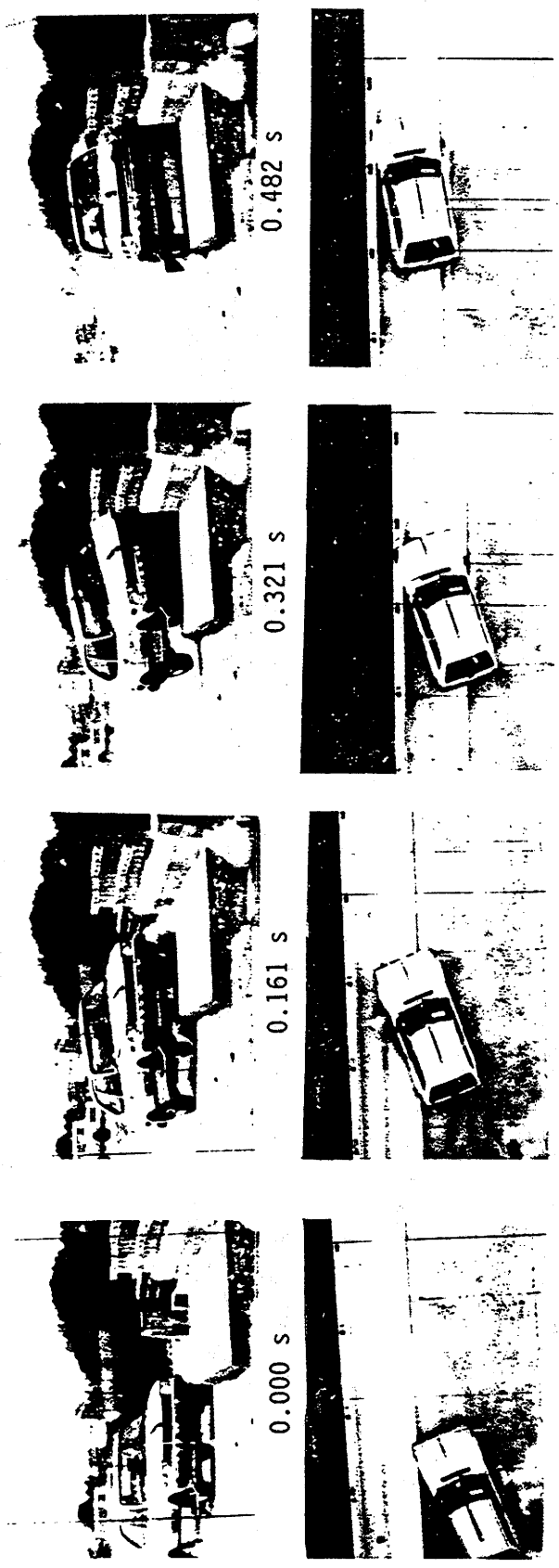
Impact Speed. . . . . . . 51.7 mi/h (83.2 km/h)
Impact Angle. . . . . . 20.8 deg
Speed at Parallel . . . 41.0 mi/h (66.0 km/h)
Exit Speed . . . . . . 40.8 mi/h (65.6 km/h)
Exit Trajectory . . . . 6.1 deg
Vehicle Accelerations
  (Max. 0.050-sec Avg) at true c.g.
  Longitudinal. . . . . . -4.4 g
  Lateral . . . . . . -6.8 g
Occupant Impact Velocity at true c.g.
  Longitudinal. . . . . . 12.2 ft/s (3.7 m/s)
  Lateral . . . . . . 6.3 ft/s (1.9 m/s)
Occupant Ridedown Accelerations
  Longitudinal. . . . . . -4.7 g
  Lateral . . . . . . -13.3 g
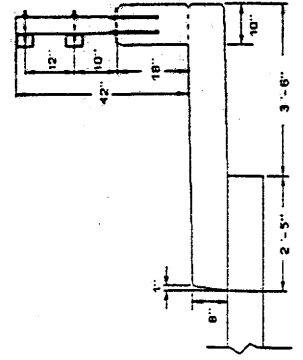
Figure 27. Summary of results for test 7069-22.

1 in = 25.4 mm

Table 5. Evaluation of crash test no. 7069-22.
{BR27D bridge railing on sidewalk [1,800 lb (817 kg)|51.7 mi/h (83.2 km/h)|20.8 degrees]}

	CRITERIA	TEST RESULTS	PASS/FAIL*
A.	Must contain vehicle	Vehicle was contained	Pass
B.	Debris shall not penetrate passenger compartment	No debris penetrated passenger compartment	Pass
C.	Passenger compartment must have essentially no deformation	No deformation	Pass
D.	Vehicle must remain upright	Vehicle did remain upright	Pass
E.	Must smoothly redirect the vehicle	Vehicle was smoothly redirected	Pass
F.	Effective coefficient of friction μ — Assessment 0 - .25 — Good .26 - .35 — Fair > .35 — Marginal	μ — Assessment .40 (Impact @ curb) — Marginal .40 (Impact @ rail) — Marginal	Pass
G.	Shall be less than Occupant Impact Velocity - ft/s (m/s) Longitudinal — Lateral 30 (9.2) — 25 (7.6) Occupant Ridedown Accelerations - g's Longitudinal — Lateral 15 — 15	Occupant Impact Velocity - ft/s (m/s) Longitudinal — Lateral 12.2 (3.7) — 6.3 (1.9) Occupant Ridedown Accelerations - g's Longitudinal — Lateral -4.7 — -13.3	Pass
H.	Exit angle shall be less than 12 degrees	Exit angle was 6.1 degrees	Pass

* A, B, C, D and G are required. E, F, and H are desired. (See table 1)

52

Test Number 7069-23

Vehicle: 1984 Chevrolet Pickup
Test Inertia Weight: 5,400 lb (2 452 kg)
Gross Static Weight: 5,565 lb (2 527 kg)
Impact Speed: 45.3 mi/h (72.9 km/h)
Impact Angle: 20.2 deg

At 0.171 s after impact the right front wheel contacted the curb and the left side of the vehicle was airborne. The vehicle impacted the concrete parapet at 0.218 s. The vehicle impacted the parapet 3 ft (0.9 m) from post 5 (between posts 4 and 5) traveling at a speed of 43.8 mi/h (70.5 km/h) and at an angle of 19.7 degrees. As the vehicle continued forward, the bumper protruded between the lower metal railing element and the concrete parapet. At 0.295 s the vehicle began to redirect. By 0.487 s the vehicle was traveling parallel to the bridge railing at a speed of 40.3 mi/h (64.8 km/h), and at 0.501 s the rear of the vehicle impacted the parapet. The vehicle lost contact with the concrete parapet at 0.587 s traveling at 37.2 mi/h (59.9 km/h) and 5.3 degrees. It was in contact with the railing for 12.8 ft (3.9 m). The brakes were applied as the vehicle left the installation. The vehicle yawed counterclockwise and subsequently came to rest 113 ft (34 m) from the point of impact resting against another barrier downstream of the bridge railing installation.

The bridge railing received minimal damage (figure 28). The maximum permanent deformation to the railing element was 0.5 in (13 mm) between posts 5 and 6. Posts 5 and 6 were also pushed rearward approximately 3/16 in (05 mm). There was only cosmetic damage to the concrete parapet. There were tire marks on the concrete parapet, on the face of the lower metal railing element in the area of impact, and also on the lower part of posts 5 and 6.

The vehicle sustained damage to the left side as shown in figure 28. Maximum crush at the left front corner at bumper height was 12.5 in (318 mm) and the right side was deformed outward 5.0 in (127 mm). Also, damage was done to the front bumper, hood, grill, radiator and fan, left front quarter panel, left door, left rear quarter panel, left front and rear tires and rims, rear bumper, and right front quarter panel and right door.

The railing contained the vehicle with minimal lateral movement of the metal railing element of the bridge railing system. There was no intrusion of railing components into the occupant compartment and no debris to present undue hazard to other traffic. The integrity of the occupant compartment was maintained with no intrusion and no deformation. The vehicle remained upright and relatively stable during the collision. The bridge railing smoothly redirected the vehicle. The effective coefficient of friction was considered good. The occupant impact velocities and the occupant ridedown accelerations were within the limits. The vehicle trajectory at loss of contact indicated minimum intrusion into adjacent traffic lanes.

Performance of the railing in this test is judged acceptable, as indicated in figure 29 and table 6.

53
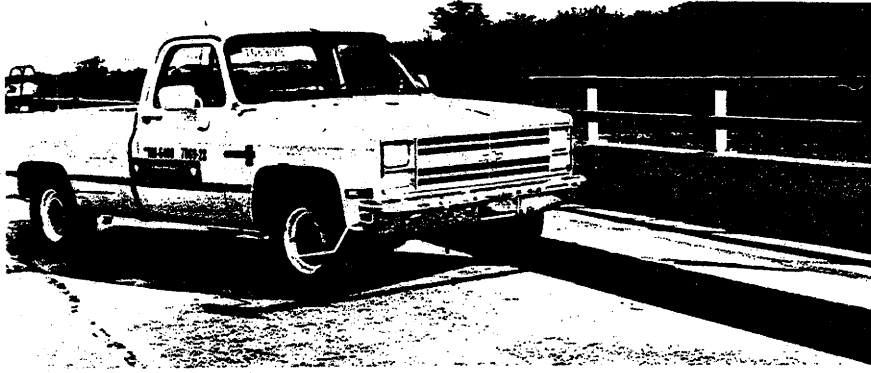
Figure 28. Vehicle and railing for test 7069-23.

54

0.000 s	0.166 s	0.332 s	0.498 s
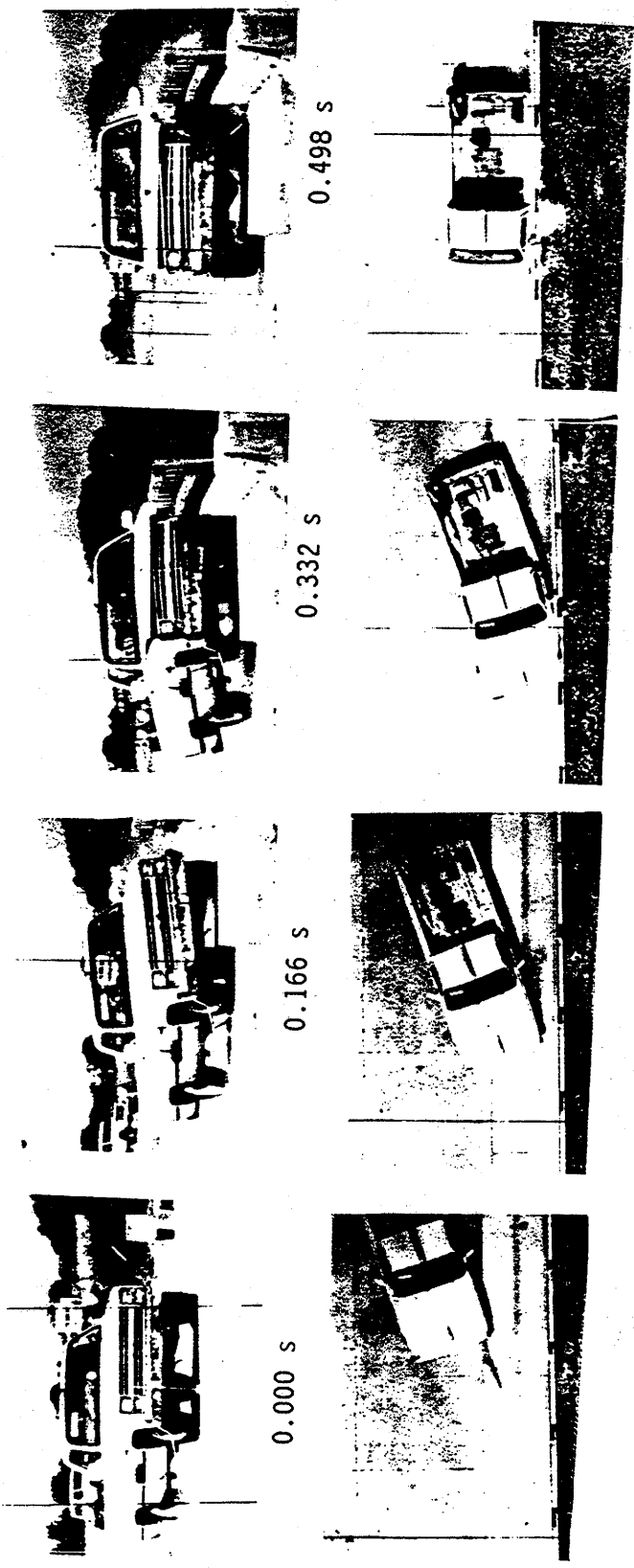
Test No. 7069-23
Date 03/26/92
Test Installation . . . . BR27D Bridge Railing
 on sidewalk
Installation Length . . 100 ft (30 m)

Test Vehicle . . . . 1984 Chevrolet
Vehicle Weight . . . . . Custom Pickup
 Test Inertia . . . . . 5,400 lb (2 452 kg)
 Gross Static . . . . 5,565 lb (2 527 kg)
Vehicle Damage Classification
 TAD . . . . 11FL4 & 11LD4
 CDC . . . . 11FLEK2 & 11LDEW3
Maximum Vehicle Crush . 12.5 in (318 mm)

Impact Speed. . . . . . . 45.3 mi/h (72.9 km/h)
Impact Angle. . . . . . . 20.2 deg
Speed at Parallel . . . 40.3 mi/h (64.8 km/h)
Exit Speed . . . . . . 37.2 mi/h (59.9 km/h)
Exit Trajectory . . . . 5.3 deg
Vehicle Accelerations
 (Max. 0.050-sec Avg) at true c.g.
 Longitudinal. . . . -3.7 g
 Lateral . . . . . -7.8 g
Occupant Impact Velocity at true c.g.
 Longitudinal. . . . 13.2 ft/s (4.0 m/s)
 Lateral . . . . . 14.0 ft/s (4.3 m/s)
Occupant Ridedown Accelerations
 Longitudinal. . . . -2.3 g
 Lateral . . . . . -10.6 g
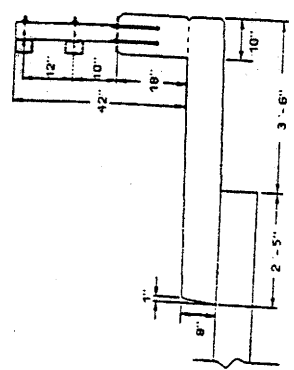
Figure 29. Summary of results for test 7069-23.

1 in = 25.4 mm

55

Table 6. Evaluation of crash test no. 7069-23.
{BR27D bridge railing on sidewalk [5,400 lb (2 452 kg)|45.3 mi/h (72.9 km/h)|20.2 degrees]}

	CRITERIA	TEST RESULTS	PASS/FAIL*
A.	Must contain vehicle	Vehicle was contained	Pass
B.	Debris shall not penetrate passenger compartment	No debris penetrated passenger compartment	Pass
C.	Passenger compartment must have essentially no deformation	No deformation	Pass
D.	Vehicle must remain upright	Vehicle did remain upright	Pass
E.	Must smoothly redirect the vehicle	Vehicle was smoothly redirected	Pass
F.	Effective coefficient of friction		Pass

μ	Assessment
0 - .25	Good
.26 - .35	Fair
> .35	Marginal

μ		Assessment
.07	(Impact @ curb)	Good
.06	(Impact @ rail)	Good

G.	Shall be less than		Pass

Occupant Impact Velocity - ft/s (m/s)

Longitudinal	Lateral
30 (9.2)	25 (7.6)

Occupant Impact Velocity - ft/s (m/s)

Longitudinal	Lateral
13.2 (4.0)	14.0 (4.3)

Occupant Ridedown Accelerations - g's

Longitudinal	Lateral
15	15

Occupant Ridedown Accelerations - g's

Longitudinal	Lateral
-2.3	-10.6

H.	Exit angle shall be less than 12 degreesrees	Exit angle was 5.3 degreesrees	Pass

* A, B, C, and D are required. E, F, G, and H are desired. (See table 1)

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BR27D on Deck

Test Number 7069-30

Vehicle:	1983 Honda Civic
Test Inertia Weight:	1,800 lb (817 kg)
Gross Static Weight:	1,970 lb (894 kg)
Impact Speed:	51.2 mi/h (82.4 km/h)
Impact Angle:	20.5 deg

Shortly after impact (0.036 s) the vehicle began to redirect and at 0.093 s the right front corner of the vehicle began to shift outward. At approximately 0.095 s after impact the dummy impacted the driver side door and shattered the door glass. The right front tire lost contact with the roadway at 0.108 s. By 0.164 s the vehicle was traveling parallel to the bridge railing at a speed of 43.6 mi/h (70.2 km/h), and at 0.178 s the rear of the vehicle impacted the parapet. The right rear tire lost contact with the roadway at 0.196 s. The vehicle lost contact with the bridge railing at 0.319 s traveling at 43.0 mi/h (69.2 km/h) and 6.8 degrees. It was in contact with the railing for 8.0 ft (2.4 m). The right front tire of the vehicle contacted the roadway again at 0.476 s and the right rear at 0.0557 s. The brakes were applied as the vehicle exited the test site. The vehicle subsequently came to rest 150 ft (46 m) down from and 70 ft (21 m) toward the traffic side of the point of impact.

The bridge railing received minimal damage (figure 30). There was no measurable permanent deformation to the railing elements and only cosmetic damage to the concrete parapet. There were tire marks on the concrete parapet and on the face of the lower metal railing element in the area of impact.

Maximum crush of the vehicle at the left front corner at bumper height was 7.0 in (178 mm) (figure 30). The left front strut was damaged and the left front wheel was canted inward at the bottom and pushed back reducing the wheelbase on the driver side by 2.25 in (57 mm). Also, damage was done to the right front quarter panel, front bumper, hood, left headlight, left front quarter panel, left door and glass, left rear quarter panel, rear bumper, and left front and rear tires and rims.

The railing contained the vehicle with no lateral movement of the metal railing element of the bridge railing system. There was no intrusion of railing components into the occupant compartment and no debris to present undue hazard to other traffic. The integrity of the occupant compartment was maintained with no intrusion and no deformation. The vehicle remained upright and relatively stable during the collision. The bridge railing smoothly redirected the vehicle. The effective coefficient of friction was considered good. The occupant impact velocities and the occupant ridedown accelerations were within the limits. The vehicle trajectory at loss of contact indicated minimum intrusion into adjacent traffic lanes.

Performance of the railing in this test is judged acceptable, as indicated in figure 31 and table 7.
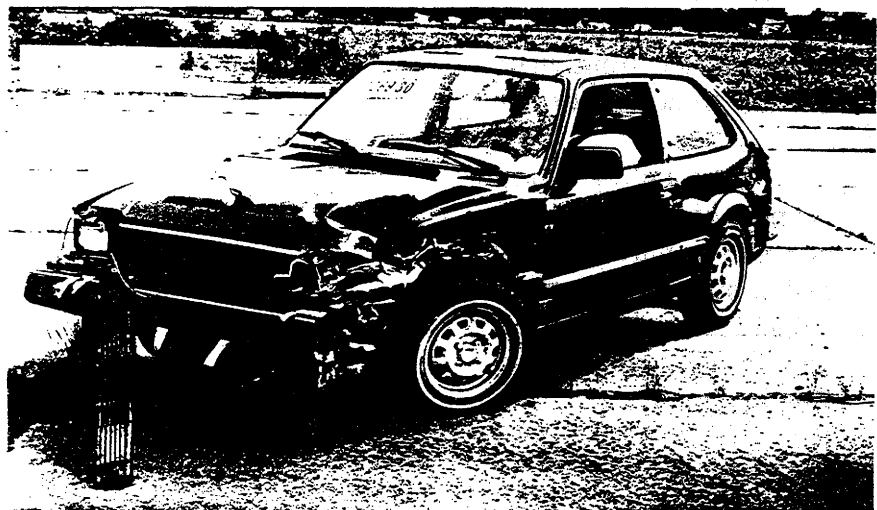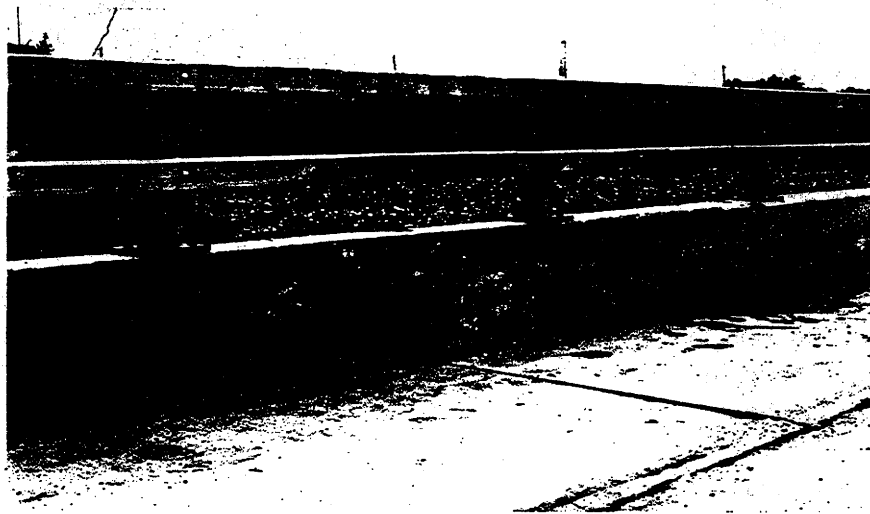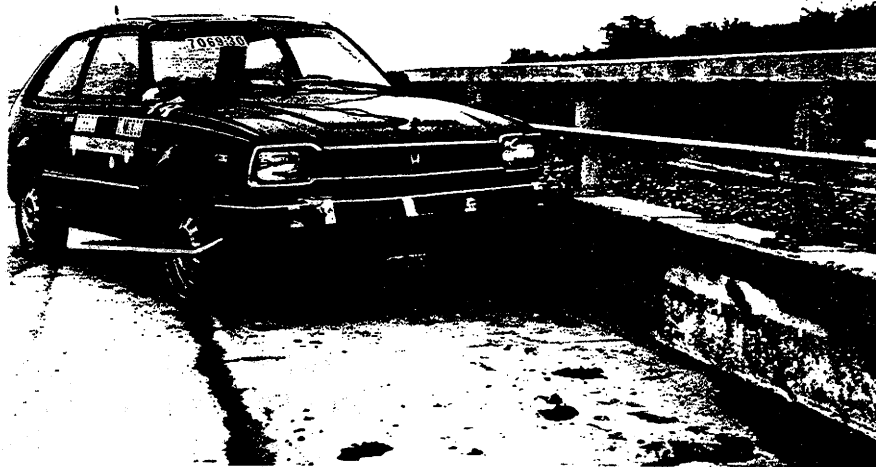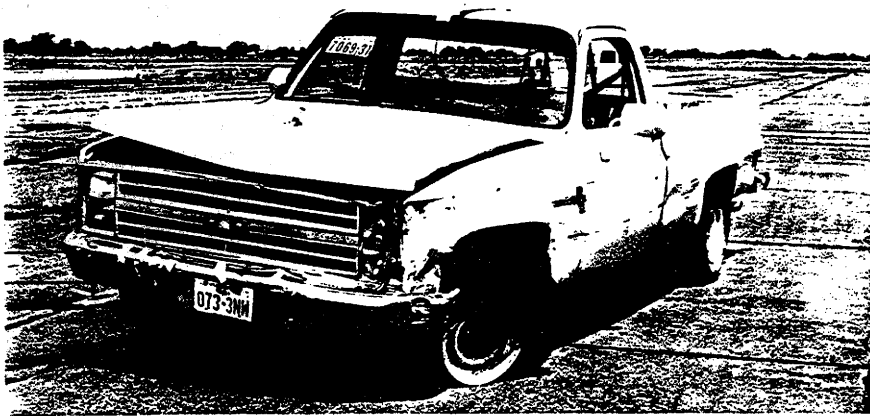
Figure 30.   Vehicle and railing for test 7069-30.

0.000 s	0.090 s	0.181 s
		0.271 s
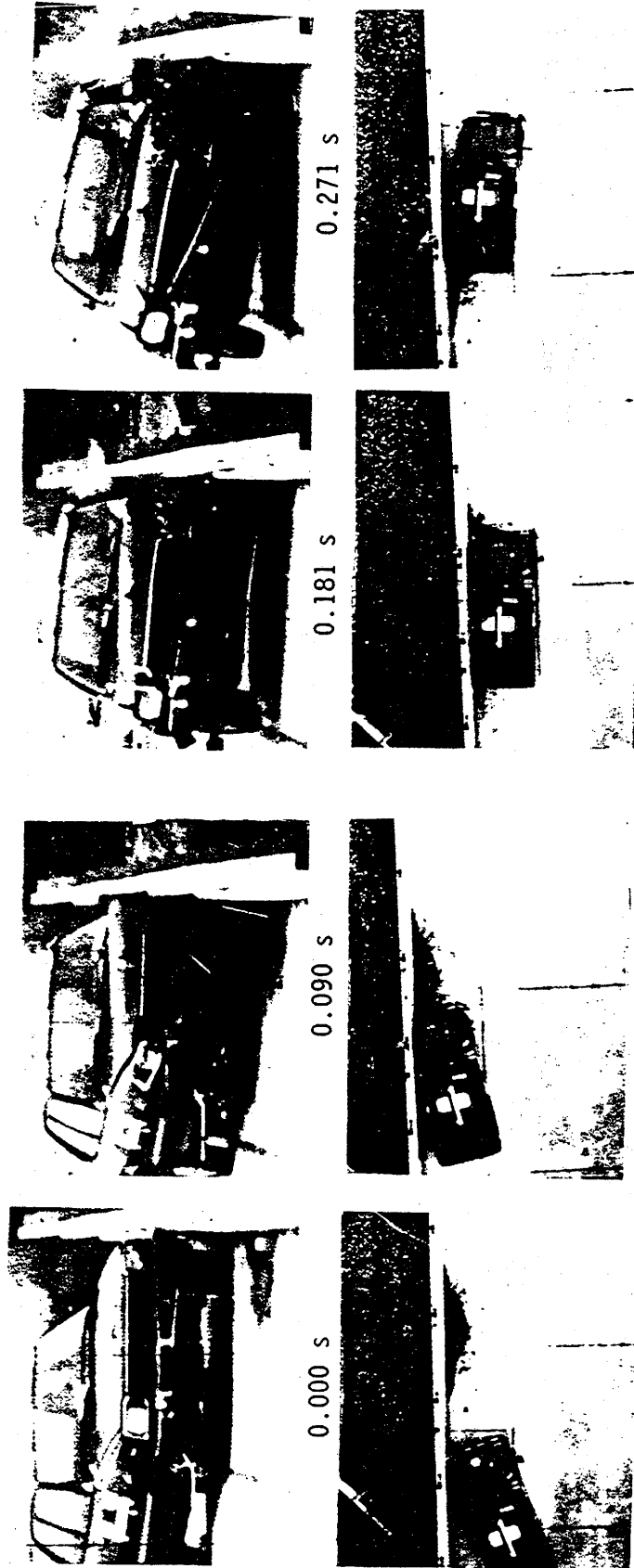
Test No. 7069-30
Date 05/19/92

Test Installation . . . BR27D Bridge Railing
                          on deck
Installation Length . . 100 ft (30 m)

Test Vehicle . . . . . . 1983 Honda Civic
Vehicle Weight
  Test Inertia . . . . . 1,800 lb (817 kg)
  Gross Static . . . . . 1,970 lb (894 kg)
Vehicle Damage Classification
  TAD 11LFQ3
  CDC . . . . 11FLEK2 & 11LFES2
Maximum Vehicle Crush . 7.0 in (178 mm)

Impact Speed. . . . . . 51.2 mi/h (82.4 km/h)
Impact Angle. . . . . . 20.5 deg
Speed at Parallel . . . 43.6 mi/h (70.2 km/h)
Exit Speed . . . . . . 43.0 mi/h (69.2 km/h)
Exit Trajectory . . . . 6.8 deg
Vehicle Accelerations
  (Max. 0.050-sec Avg) at true c.g.
  Longitudinal. . . . . -7.5 g
  Lateral . . . . -12.8 g
Occupant Impact Velocity at true c.g.
  Longitudinal. . . . . 16.0 ft/s (4.9 m/s)
  Lateral . . . . 21.5 ft/s (6.6 m/s)
Occupant Ridedown Accelerations
  Longitudinal. . . . . -3.6 g
  Lateral . . . . -6.1 g
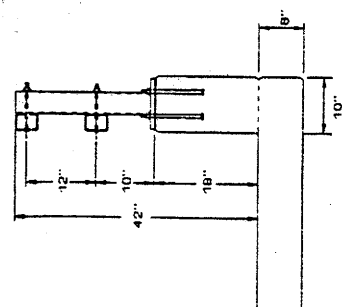
Figure 31. Summary of results for test 7069-30.

1 in = 25.4 mm

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Table 7. Evaluation of crash test no. 7069-30.
{BR27D bridge railing on deck [1,800 lb (817 kg)|51.2 mi/h (82.4 km/h)|20.5 degrees]}

	CRITERIA	TEST RESULTS	PASS/FAIL*
A.	Must contain vehicle	Vehicle was contained	Pass
B.	Debris shall not penetrate passenger compartment	No debris penetrated passenger compartment	Pass
C.	Passenger compartment must have essentially no deformation	No deformation	Pass
D.	Vehicle must remain upright	Vehicle did remain upright	Pass
E.	Must smoothly redirect the vehicle	Vehicle was smoothly redirected	Pass
F.	Effective coefficient of friction		Pass

μ	Assessment
0 - .25	Good
.26 - .35	Fair
> .35	Marginal

μ	Assessment
.24	Good

G. Shall be less than

Occupant Impact Velocity - ft/s (m/s)

Longitudinal	Lateral
30 (9.2)	25 (7.6)

Occupant Ridedown Accelerations - g's

Longitudinal	Lateral
15	15

Occupant Impact Velocity - ft/s (m/s)

Longitudinal	Lateral
16.0 (4.9)	21.5 (6.6)

Occupant Ridedown Accelerations - g's

Longitudinal	Lateral
-3.6	-6.1

Pass

H. Exit angle shall be less than 12 degrees   Exit angle was 6.8 degrees   Pass

* A, B, C, D and G are required. E, F, and H are desired. (See table 1)

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Vehicle: 1985 Chevrolet Pickup
Test Inertia Weight: 5,400 lb (2 452 kg)
Gross Static Weight: 5,566 lb (2 527 kg)
Impact Speed: 45.6 mi/h (73.4 km/h)
Impact Angle: 18.8 deg

At 0.020 s after impact the left front wheel contacted the concrete parapet, and at 0.029 s the right front corner of the vehicle began to deform outward. The vehicle began to redirect at 0.048 s after impact, and at 0.148 s the dummy impacted the driver side door and shattered the glass. By 0.231 s the vehicle was traveling parallel to the bridge railing at a speed of 40.8 mi/h (65.6 km/h), and shortly thereafter the rear of the vehicle impacted the parapet. The vehicle lost contact with the bridge railing at 0.333 s traveling at 38.0 mi/h (61.1 km/h) and 6.2 degrees. It was in contact with the railing for 11.7 ft (3.6 m). The brakes were applied 2.3 s after impact. The vehicle yawed counterclockwise due to the deflated left front tire and subsequently came to rest 225 ft (69 m) down from and 40 ft (12 m) behind the point of impact.

The bridge railing received minimal damage (figure 32). The maximum permanent deformation to the railing element was 0.5 in (13 mm) between posts 5 and 6. There was only cosmetic damage to the concrete parapet. There were tire marks on the concrete parapet, on the face of the lower metal railing element in the area of impact, and also on the lower part of post 6.

Maximum crush of the vehicle at the left front corner at bumper height was 6.5 in (165 mm), and the right side was deformed outward 4.0 in (102 mm) (figure 32). Also, damage was done to the front bumper, hood, grill, left front quarter panel, left door, left rear quarter panel, left front and rear tires and rims, rear bumper, and right front quarter panel and right door.

The railing contained the vehicle with minimal lateral movement of the metal railing element of the bridge railing system. There was no intrusion of railing components into the occupant compartment and no debris to present undue hazard to other traffic. The integrity of the occupant compartment was maintained with no intrusion and no deformation. The vehicle remained upright and relatively stable during the collision. The bridge railing smoothly redirected the vehicle. The effective coefficient of friction was considered good. The occupant impact velocities and the occupant ridedown accelerations were within the limits. The vehicle trajectory at loss of contact indicated minimum intrusion into adjacent traffic lanes.

Performance of the railing in this test is judged acceptable, as indicated in figure 33 and table 8.
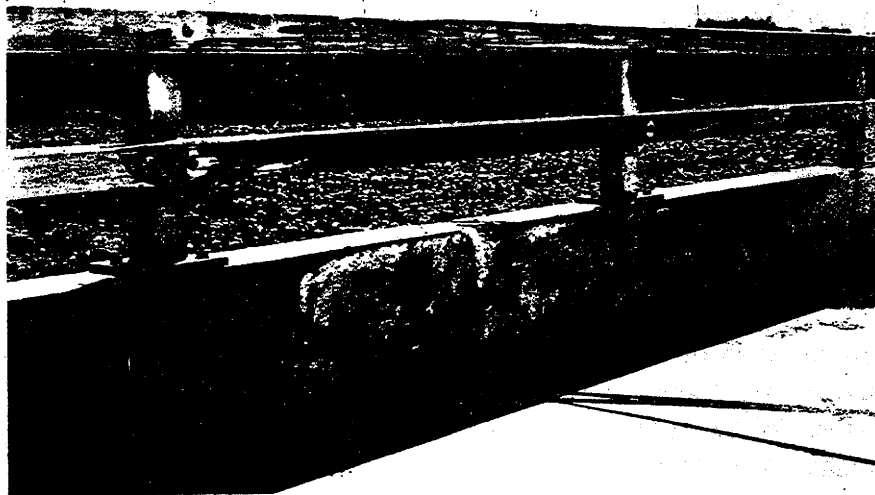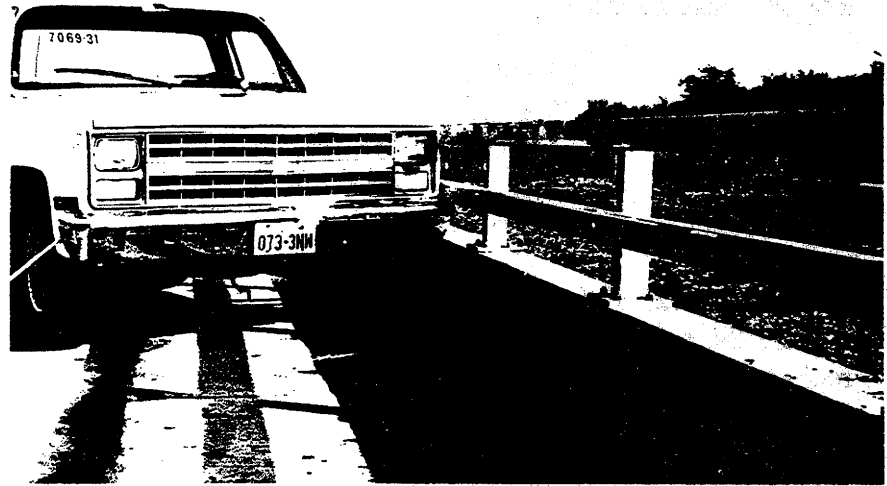
Figure 32.   Vehicle and railing for test 7069-31.

0.000 s	0.095 s	0.191 s	0.286 s
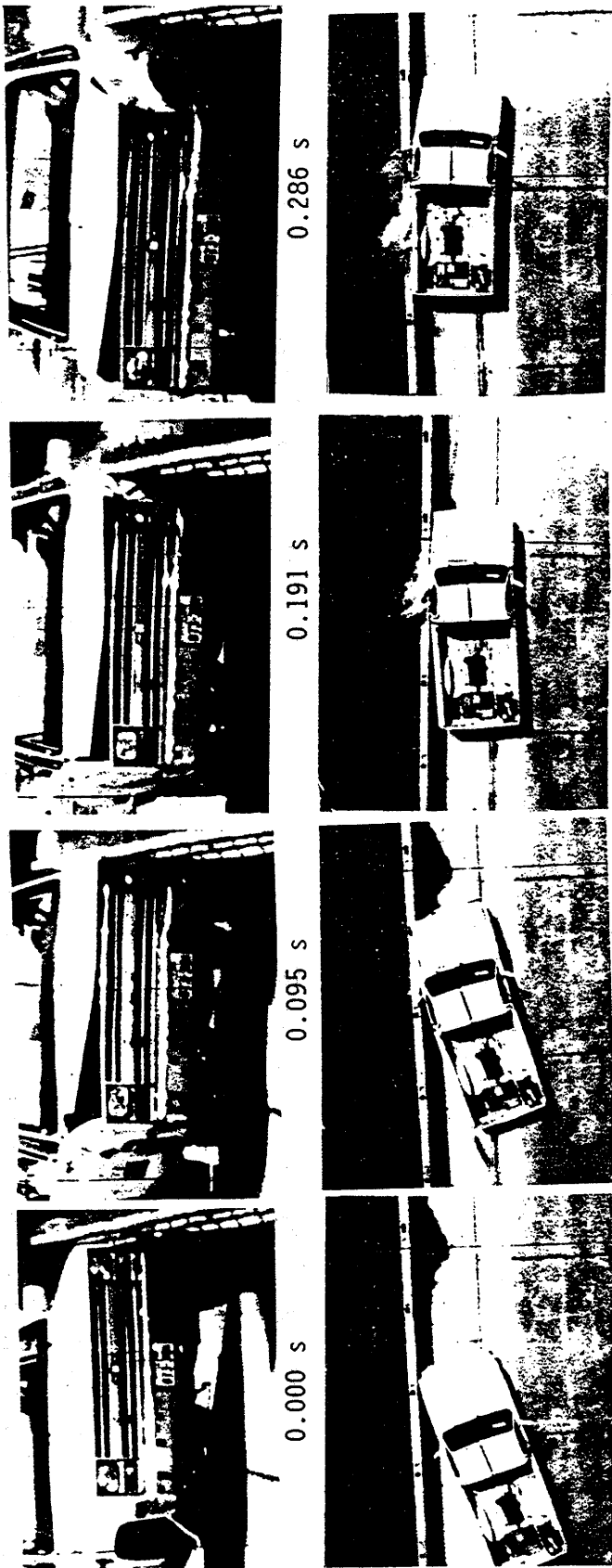
Test No. . . . . : 7069-31
Date . . . . : 05/21/92
Test Installation . . . : BR27D Bridge Railing
                          on deck
Installation Length . . : 100 ft (30 m)

Test Vehicle . . . . . . : 1985 Chevrolet
Vehicle Weight . . . . . : Custom Pickup
  Test Inertia . . . . . : 5,400 lb (2 452 kg)
  Gross Static . . . . . : 5,566 lb (2 527 kg)
Vehicle Damage Classification
  TAD . . . . : 11LFQ3 & 11LD2
  CDC . . . . : 11FLEK2 & 11LDEW2
Maximum Vehicle Crush . : 6.5 in (165 mm)

Impact Speed. . . . . . : 45.6 mi/h (73.4 km/h)
Impact Angle. . . . . . : 18.8 deg
Speed at Parallel . . . : 40.8 mi/h (65.6 km/h)
Exit Speed . . . . . . : 38.0 mi/h (61.1 km/h)
Exit Trajectory . . . . : 6.2 deg
Vehicle Accelerations
  (Max. 0.050-sec Avg) at true c.g.
  Longitudinal. . . : -4.1 g
  Lateral . . . . . : -7.5 g
Occupant Impact Velocity at true c.g.
  Longitudinal. . . : 11.7 ft/s (3.6 m/s)
  Lateral . . . . . : 12.3 ft/s (3.7 m/s)
Occupant Ridedown Accelerations
  Longitudinal. . . : 2.2 g
  Lateral . . . . . : -8.2 g
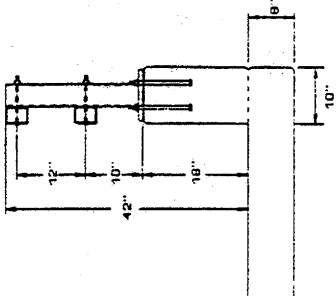
Figure 33. Summary of results for test 7069-31.

1 in = 25.4 mm

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Table 8. Evaluation of crash test no. 7069-31.
{BR27D bridge railing on deck [5,400 lb (2 452 kg)|45.6 mi/h (73.4 km/h)|18.8 degrees]}

	CRITERIA	TEST RESULTS	PASS/FAIL*
A.	Must contain vehicle	Vehicle was contained	Pass
B.	Debris shall not penetrate passenger compartment	No debris penetrated passenger compartment	Pass
C.	Passenger compartment must have essentially no deformation	No deformation	Pass
D.	Vehicle must remain upright	Vehicle did remain upright	Pass
E.	Must smoothly redirect the vehicle	Vehicle was smoothly redirected	Pass
F.	Effective coefficient of friction μ Assessment 0 - .25 Good .26 - .35 Fair > .35 Marginal	μ Assessment .16 Good	Pass
G.	Shall be less than		
	Occupant Impact Velocity - ft/s (m/s) Longitudinal Lateral 30 (9.2) 25 (7.6)	Occupant Impact Velocity - ft/s (m/s) Longitudinal Lateral 11.7 (3.6) 12.3 (3.7)	Pass
	Occupant Ridedown Accelerations - g's Longitudinal Lateral 15 15	Occupant Ridedown Accelerations - g's Longitudinal Lateral 2.2 -8.2	Pass
H.	Exit angle shall be less than 12 degrees	Exit angle was 6.2 degrees	Pass

* A, B, C, and D are required. E, F, G, and H are desired. (See table 1)

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PERFORMANCE LEVEL TWO RAILINGS

Seven railing designs were tested to performance level two as shown in table 9. Acceptable performance was obtained in all tests.

The original Illinois 2399 railing design was proposed as a retrofit railing. The modified prototype (Illinois 2399-1) was tested on a cantilevered slab that simulated situations where it would be used as a retrofit, but it is deemed suitable for new construction if adequate bridge deck strength is provided.

Posts used in the test installation were somewhat larger than needed based on strength calculations and the railing functioned as a "rigid" system in tests. In test 7069-1 with the small automobile, there was no damage to the railing. There was a small amount of permanent deformation of the metal railing in the test with a pickup (7069-2). In the test with an 18,000-lb (8 172-kg) truck, moderate damage occurred to the railing. Bolts connecting the lower rail element to the posts were sheared at five consecutive posts in the impact area; however, the rail element remained reasonably well in place. At one post the upper rail element mounting bolt was sheared. Results of the tests show that acceptable performance was obtained.

The 32-in (813-mm) concrete parapet is a simple, effective railing system that meets performance level two requirements. It showed no structural distress in the tests performed. One could argue that when compared to the New Jersey or F-shape, the vertical-faced parapet imposes slightly higher accelerations and slightly more damage but provides slightly more stability to the vehicle.

The 32-in (813-mm) New Jersey safety shape has been subjected to extensive full-scale crash testing with various vehicles in many other research studies and is used extensively throughout the Nation. It was included in this study for testing with a 5,400-lb (2 452-kg) pickup and an 18,000-lb (8 172-kg) single unit truck under conditions meeting performance level two of the 1989 guide specifications.[3] Acceptable performance was obtained in both tests.

The 32-in (813-mm) F-shape was subjected to tests for performance level two as shown in table 10. The 18,000-lb (8 172-kg) truck test was repeated twice because the speed was too slow in the first two attempts. This was caused by two unrelated equipment malfunctions.

The railing functioned acceptably in all tests, and it is recommended as a suitable alternative to the 32-in (813-mm) vertical faced concrete parapet and the 32-in (813-mm) New Jersey safety shape.

Two versions of railing BR27C were tested to performance level two requirements. The first version was mounted on an 8-in (200-mm) high 5-ft (1.5-m) wide sidewalk and the second was mounted on the deck. Both versions performed acceptably.

Railing BR27C on sidewalk was tested first and two details of the design were changed for BR27C on deck. The rail-to-post connection bolts were changed from 1/2 in (13 mm) diameter to 3/4 in (19 mm) diameter and an anchorage assembly was added at the end of the anchor bolts. These modifications are recommended for both versions of the railing.

The Illinois side-mounted railing consists of two tubular rail elements mounted on steel wide flange posts. The posts are mounted on the side face of prestressed slab planks with anchor bolts screwed into inserts cast in the planks. Blockouts are used between the posts and planks to provide additional useable bridge width.

The railing was subjected to tests for performance level two and performed acceptably in all tests.

Some difficulty was encountered in installation of the anchor bolts. All hardware was galvanized and galling of the anchor bolt threads occurred. It was necessary to chase the threads to obtain suitable engagement of the anchor bolts in the inserts.

Table 9. Summary of full-scale crash tests performed on performance level two railings.

RAILING DESIGN	TEST NO.	TEST DATE	ACTUAL CONDITIONS	DESIGN CONDITIONS	COMMENTS
ILLINOIS 2399-1	7069-1	7/14/87	1,795 lb|58.7 mi/h|20.0 deg (815 kg|94.4 km/h|20.0 deg)	1,800 lb|60 mi/h|20 deg (817 kg|96.5 km/h|20 deg)	Marginal
	7069-2	7/24/87	5,450 lb|63.6 mi/h|19.2 deg (2 474 kg|102.3 km/h|19.2 deg)	5,400 lb|65 mi/h|20 deg (2 452 kg|104.6 km/h|20 deg)	Acceptable
	7069-15	9/13/88	18,000 lb|50.8 mi/h|15.1 deg (8 172 kg|81.7 km/h|15.1 deg)	18,000 lb|50 mi/h|15 deg (8 172 kg|80.5 km/h|15 deg)	Acceptable
32-in (813-mm) PARAPET	7069-5	9/24/87	1,800 lb|60.5 mi/h|21.0 deg (817 kg|97.3 km/h|21.0 deg)	1,800 lb|60 mi/h|20 deg (817 kg|96.5 km/h|20 deg)	Marginal
	7069-6	10/8/87	5,420 lb|59.7 mi/h|20.2 deg (2 461 kg|96.1 km/h|20.2 deg)	5,400 lb|60 mi/h|20 deg (2 452 kg|96.5 km/h|20 deg)	Acceptable
	7069-16	10/13/88	18,000 lb|50 mi/h|14.0 deg (8 172 kg|80.5 km/h|14.0 deg)	18,000 lb|50 mi/h|15 deg (8 172 kg|80.5 km/h|15 deg)	Acceptable
32-in (813-mm) N.J. SAFETY SHAPE	7069-12	6/22/88	18,000 lb|51.6 mi/h|15.5 deg (8 172 kg|83.0 km/h|15.5 deg)	18,000 lb|50 mi/h|15 deg (8 172 kg|80.5 km/h|15 deg)	Acceptable
	7069-14	8/11/88	5,390 lb|57.7 mi/h|20.6 deg (2 447 kg|92.8 km/h|20.6 deg)	5,400 lb|60 mi/h|20 deg (2 452 kg|96.5 km/h|20 deg)	Acceptable
	7069-3	7/28/87	1,800 lb|60.1 mi/h|21.4 deg (817 kg|96.7 km/h|21.4 deg)	1,800 lb|60 mi/h|20 deg (817|96.5 km/h|20 deg)	Acceptable
32-in (813-mm) F-SHAPE	7069-4	7/30/87	5,440 lb|65.4 mi/h|20.4 deg (2 470 kg|105.2 km/h|20.4 deg)	5,400 lb|65 mi/h|20 deg (2,452 kg|104.6 km/h|20 deg)	Acceptable
	7069-8	1/28/88	18,050 lb|46.7 mi/h|15.0 deg (8 195 kg|75.1 km/h|15.0 deg)	18,000 lb|50 mi/h|15 deg (8 172 kg|80.5 km/h|15 deg)	Speed low
	7069-9	2/23/88	18,050 lb|47.3 mi/h|15.3 deg (8 195 kg|76.1 km/h|15.3 deg)	18,000 lb|50 mi/h|15 deg (8 172 kg|80.5 km/h|15 deg)	Speed low
	7069-11	3/30/88	18,000 lb|52.1 mi/h|14.8 deg (8 172 kg|83.8 km/h|14.8 deg)	18,000 lb|50 mi/h|20 deg (8 172 kg|80.5 km/h|20 deg)	Acceptable

Table 9. Summary of full-scale crash tests performed on performance level two railings (continued).

RAILING DESIGN	TEST NO.	TEST DATE	ACTUAL CONDITIONS	DESIGN CONDITIONS	COMMENTS
BR27C ON SIDEWALK	7069-24	3/31/92	1,800 lb|61.7 mi/h|18.7 deg (817 kg|99.3 km/h|18.7 deg)	1,800 lb|60 mi/h|20 deg (817 kg|96.5 km/h|20 deg)	Acceptable
	7069-25	4/2/92	5,400 lb|62.6 mi/h|19.4 deg (2 452 kg|100.7 km/h|19.4 deg)	5,400 lb|60 mi/h|20 deg (2 452 kg|96.5 km/h|20 deg)	Acceptable
	7069-26	4/8/92	18,000 lb|51.0 mi/h|13.7 deg (8 172 kg|82.0 km/h|13.7 deg)	18,000 lb|50 mi/h|15 deg (8 172 kg|80.5 km/h|15 deg)	Acceptable
BR27C ON DECK	7069-32	7/14/92	1,800 lb|60.3 mi/h|19.8 deg (817 kg|97.0 km/h|19.8 deg)	1,800 lb|60 mi/h|20 deg (817 kg|96.5 km/h|20 deg)	Acceptable
	7069-33	7/16/92	5,400 lb|55.3 mi/h|19.6 deg (2 452 kg|89.0 km/h|19.6 deg)	5,400 lb|60 mi/h|20 deg (2 452 kg|96.5 km/h|20 deg)	Acceptable
	7069-34	8/12/92	18,000 lb|52.5 mi/h|12.8 deg (8 172 kg|84.5 km/h|12.8 deg)	18,000 lb|50 mi/h|15 deg (8 172 kg|80.5 km/h|15 deg)	Acceptable
ILLINOIS SIDE MOUNT	7069-35	3/23/93	1,800 lb|59.9 mi/h|20.1 deg (817 kg|96.4 km/h|20.1 deg)	1,800 lb|60 mi/h|20 deg (817 kg)|6.5 km/h|20 deg)	Acceptable
	7069-36	3/25/93	5,400 lb|60.4 mi/h|20.4 deg (2 452 kg|97.2 km/h|20.4 deg)	5,400 lb|60 mi/h|20 deg (2 452 kg|96.5 km/h|20 deg)	Acceptable
	7069-37	4/30/93	18,000 lb|51.4 mi/h|14.7 deg (8 172 kg|82.7 km/h|14.7 deg)	18,000 lb|50 mi/h|15 deg (8 172 kg|80.5 km/h|15 deg)	Acceptable

Illinois 2399-1 Railing

Test Number 7069-1

Vehicle:	1980 Honda
Test Inertia Weight:	1,795 lb (815 kg)
Gross Static Weight:	1,961 lb (890 kg)
Impact Speed:	58.7 mi/h (94.4 km/h)
Impact Angle:	20.0 deg

The vehicle impacted the barrier midway between posts 6 and 7. At approximately 0.020 s after impact the right front tire contacted the curb, and by 0.030 s the vehicle began to redirect. As the tire and rim rode against the curb, the tire aired-out. The frame around the windshield began to deform and at about 0.070 s the windshield broke. At 0.151 s the vehicle was traveling parallel with the railing and at 0.168 s the rear of the vehicle impacted the railing. The vehicle lost contact with the railing at 0.226 s after impact. It was in contact with the lower rail element for 9.7 ft (2.9 m). As the vehicle exited the railing, the brakes were applied and the vehicle yawed slightly in clockwise rotation. The vehicle subsequently came to rest 225 ft (69 m) downstream and 21 ft (6 m) toward the field side of the point of impact.

The railing received very little damage (figure 34). There were tire marks on the face of the railings and the curb and minor chips on the edge of the curb. There was no measurable movement or deformation in the railing.

The vehicle sustained extensive damage to the right front (figure 34). Maximum crush at the right front corner at bumper height was 8.0 in (203 mm). The right front tire was deflated, the rim was bent, and the suspension was damaged. The front bumper was disconnected on the left side but still attached on the right side. The passenger door was bent and jammed and the right rear quarter panel was bent and scraped. The hood was bent and shifted to the left. The windshield frame was bent and the windshield was broken and partially out. The roof of the vehicle was twisted.

The railing contained and smoothly redirected the vehicle with no lateral movement of the railing. There were no debris or detached elements. There was minimal intrusion into the occupant compartment. The vehicle trajectory at loss of contact indicates minimum intrusion into adjacent traffic lanes. The vehicle remained upright and stable during the entire test period.

Due to the slightly high lateral occupant impact velocity of 25.1 ft/s (7.7 m/s), performance of the railing in this test is considered marginally acceptable (as indicated in figure 35 and table 10).
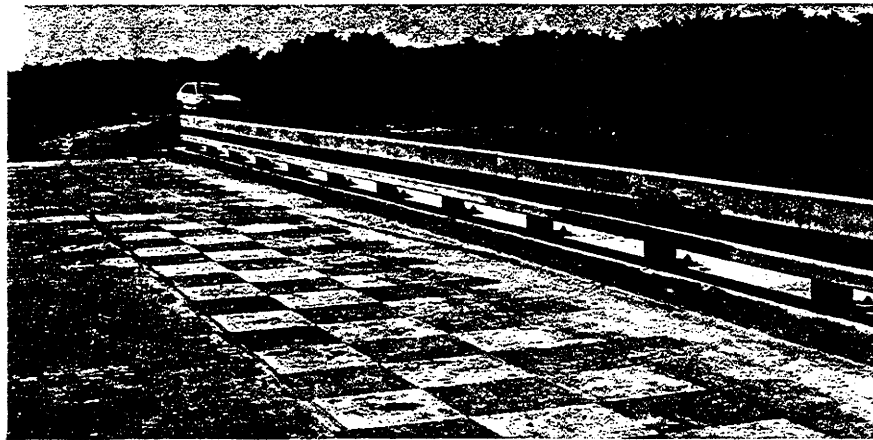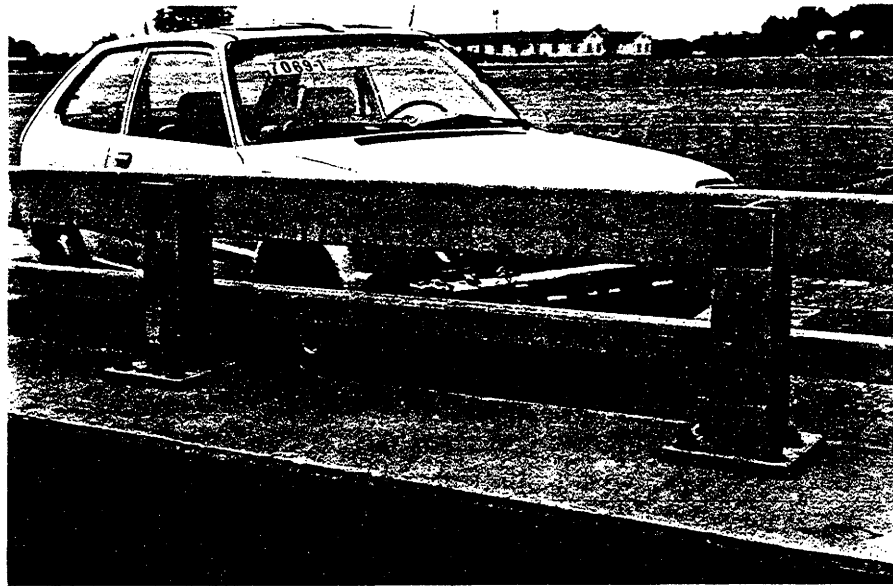
Figure 34. Vehicle and railing for test 7069-1.

0.000 s   0.058 s   0.115 s   0.200 s

Test No. . . . . : 7069-1
Date . . . . : 7/14/87
Test Installation . . . : Illinois 2399-1
                          Bridge Railing
Installation Length . . . 100 ft (30 m)
Vehicle . . . . 1980 Honda
Vehicle Weight
  Test Inertia . . . . . . 1,795 lb (815 kg)
  Gross Static . . . . . . 1,961 lb (890 kg)
Vehicle Damage Classification
  TAD 01RFQ5
  CDC . . . . 01FREK2 & 01RFEW3
Maximum Vehicle Crush . . 8.0 in (203 mm)
Max. Dyn. Rail Deflct. . Nil
Max. Perm. Rail Deform . None

Impact Speed. . . . . 58.7 mi/h (94.4 km/h)
Impact Angle. . . . . 20.0 deg
Exit Speed. . . . . . 48.5 mi/h (78.0 km/h)
Exit Angle. . . . . . 5.2 deg
Vehicle Accelerations
  (Max. 0.050-sec Avg)
  Longitudinal. . . -6.4 g
  Lateral . . . . . 14.2 g
Occupant Impact Velocity
  Longitudinal. . . 16.9 ft/s (5.2 m/s)
  Lateral . . . . . 25.1 ft/s (7.7 m/s)
Occupant Ridedown Accelerations
  Longitudinal. . . -1.4 g
  Lateral . . . . . 8.5 g

1 in = 25.4 mm

Figure 35. Summary of results for test 7069-1.

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Table 10. Evaluation of crash test no. 7069-1.
{Illinois 2399-1 Railing [1,795 lb (815 kg)|58.7 mi/h (94.4 km/h)|20.0 degrees]}

	CRITERIA	TEST RESULTS	PASS/FAIL*
A.	Must contain vehicle	Vehicle was contained	Pass
B.	Debris shall not penetrate passenger compartment	No debris penetrated passenger compartment	Pass
C.	Passenger compartment must have essentially no deformation	Acceptable deformation	Pass
D.	Vehicle must remain upright	Vehicle did remain upright	Pass
E.	Must smoothly redirect the vehicle	Vehicle was smoothly redirected	Pass
F.	Effective coefficient of friction		
	μ Assessment 0 - .25 Good .26 - .35 Fair > .35 Marginal	μ Assessment .28 Fair	Pass
G.	Shall be less than		
	Occupant Impact Velocity - ft/s (m/s) Longitudinal Lateral 30 (9.2) 25 (7.6)	Occupant Impact Velocity - ft/s (m/s) Longitudinal Lateral 16.9 (5.2) 25.1 (7.7)	Pass
	Occupant Ridedown Accelerations - g's Longitudinal Lateral 15 15	Occupant Ridedown Accelerations - g's Longitudinal Lateral -1.4 8.5	Pass
H.	Exit angle shall be less than 12 degrees	Exit angle was 5.2 degrees	Pass

* A, B, C, D and G are required. E, F, and H are desired. (See table 1)

72

<u>Test Number 7069-2</u>

Vehicle:	1981 Chevrolet Pickup
Test Inertia Weight:	5,450 lb (2 474 kg)
Gross Static Weight:	5,797 lb (2 632 kg)
Impact Speed:	63.6 mi/h (102.3 km/h)
Impact Angle:	19.2 deg

The vehicle impacted the barrier midway between posts 6 and 7. At approximately 0.017 s after impact the right front tire contacted the curb, and by 0.032 s the vehicle began to redirect. As the vehicle continued forward, the wheel rim rubbed the edge of the curb chipping off pieces of concrete. The dummies began to move abruptly to the right at 0.057 s, and at 0.063 s the passenger dummy impacted the right door so hard it knocked the top portion ajar. By 0.069 s the left front tire of the vehicle went airborne. The rear of the vehicle hit the railing at 0.154 s, and at 0.169 s the path of the vehicle c.g. was parallel with the railing. The vehicle was in contact with the railing for 14.5 ft (4.4 m) It lost contact with the railing at 0.234 s after impact. As the vehicle exited the railing, it had a yaw angle of 1.0 degree and a trajectory path of 5.8 degrees. The vehicle brakes were applied and the vehicle subsequently came to rest 270 ft (82 m) downstream from the point of impact.

The railing received moderate damage (figure 36). There were tire marks on the face of the railings and the curb and minor chips on the edge of the curb. The maximum dynamic deflection of the railing was 2.4 in (61 mm) and maximum permanent deformation was 0.5 in (13 mm). The front of the base plate on post 6 was pulled up slightly and the concrete was chipped around the bolts to the rear of the base plate.

The vehicle sustained extensive damage to the right front corner (figure 36). Maximum crush at the right front corner at bumper height was 5.0 in (127 mm). The right front and right rear wheel rims were bent and the wheel assembly and suspension damaged. The passenger door was bent and jammed and the right rear panel was dented and scraped. The hood was bent and shifted to the left. The windshield frame was bent and the windshield was cracked. The cab of the vehicle was twisted and the frame was bent.

The railing contained and smoothly redirected the vehicle with minimal lateral movement of the railing. There were no debris or detached elements. There was no intrusion into the occupant compartment. The vehicle trajectory at loss of contact indicated minimum intrusion into adjacent traffic lanes. The vehicle remained upright and stable during the entire test period.

Performance of the railing in this test is judged acceptable, as indicated in figure 37 and table 11.

73
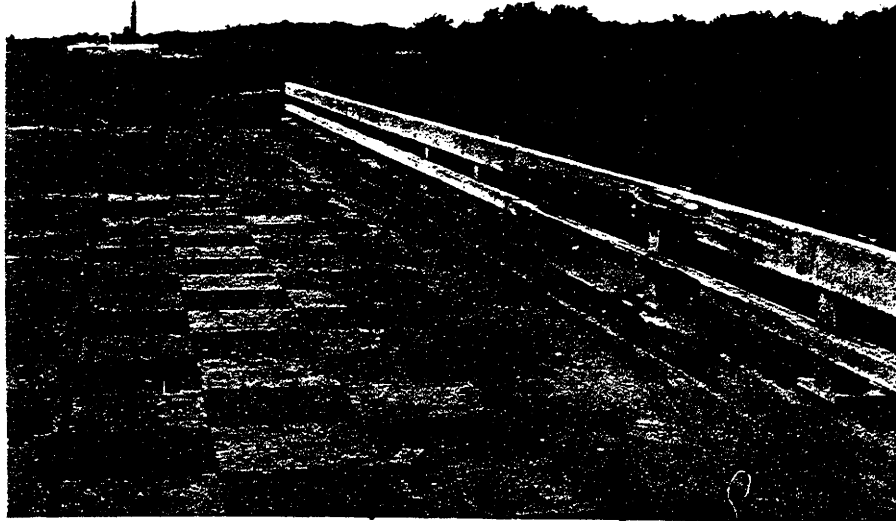
Figure 36. Vehicle and railing for test 7069-2.

74

0.000 s	0.074 s	0.149 s	0.285 s

Test No. . . . . : 7069-2
Date . . . . : 7/24/87
Test Installation . . . : Illinois 2399-1
                          Bridge Railing
Installation Length . . : 100 ft (30 m)
Vehicle . . . . : 1981 Chevrolet
                          Pickup
Vehicle Weight
    Test Inertia . . . . : 5,450 lb (2 474 kg)
    Gross Static . . . . : 5,797 lb (2 632 kg)
Vehicle Damage Classification
    TAD . . . . : 01RD4
    CDC . . . . : 01FREK1 & 01RYEW2
Maximum Vehicle Crush . : 5.0 in (127 mm)
Max. Dyn. Rail Deflct. . : 2.4 in (61 mm)
Max. Perm. Rail Deform . : 0.5 in (13 mm)

Impact Speed. . . . . . : 63.6 mi/h (102.3 km/h)
Impact Angle. . . . . . : 19.2 deg
Exit Speed. . . . . . . : 57.6 mi/h (92.7 km/h)
Exit Trajectory . . . . : 5.8 deg
Vehicle Accelerations
    (Max. 0.050-sec Avg)
    Longitudinal. . . . : -3.8 g
    Lateral . . . . . . : 14.3 g
Occupant Impact Velocity
    Longitudinal. . . . : 8.5 ft/s (2.6 m/s)
    Lateral . . . . . . : 24.6 ft/s (7.5 m/s)
Occupant Ridedown Accelerations
    Longitudinal. . . . : -1.1 g
    Lateral . . . . . . : 12.8 g
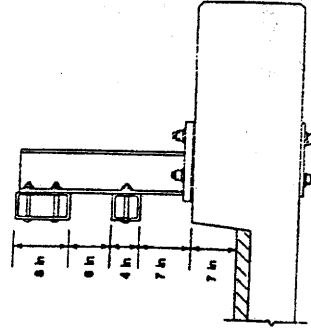
1 in = 25.4 mm

Figure 37. Summary of results for test 7069-2.

75

Table 11. Evaluation of crash test no. 7069-2.
{[Illinois 2399-1 Railing [5,450 lb (2 474 kg)|63.6 mi/h (102.3 km/h)|19.2 degrees]}

CRITERIA	TEST RESULTS	PASS/FAIL*
A. Must contain vehicle	Vehicle was contained	Pass
B. Debris shall not penetrate passenger compartment	No debris penetrated passenger compartment	Pass
C. Passenger compartment must have essentially no deformation	Minimal deformation	Pass
D. Vehicle must remain upright	Vehicle did remain upright	Pass
E. Must smoothly redirect the vehicle	Vehicle was smoothly redirected	Pass
F. Effective coefficient of friction $\underline{\mu}$ $\underline{\text{Assessment}}$ 0 - .25 Good .26 - .35 Fair > .35 Marginal	$\underline{\mu}$ $\underline{\text{Assessment}}$ .12 Good	Pass
G. Shall be less than Occupant Impact Velocity - ft/s (m/s) Longitudinal Lateral 30 (9.2) 25 (7.6) Occupant Ridedown Accelerations - g's Longitudinal Lateral 15 15	Occupant Impact Velocity - ft/s (m/s) Longitudinal Lateral 8.5 (2.6) 24.6 (7.5) Occupant Ridedown Accelerations - g's Longitudinal Lateral -1.1 12.8	Pass Pass
H. Exit angle shall be less than 12 degrees	Exit angle was 5.8 degrees	Pass

* A, B, C, and D are required. E, F, G, and H are desired. (See table 1)

76

Vehicle:	1980 Ford Single-Unit Truck
Test Inertia Weight:	18,000 lb (8 172 kg)
Empty Weight:	12,320 lb (5 593 kg)
Impact Speed:	50.8 mi/h (81.7 km/h)
Impact Angle:	15.1 deg

The vehicle impacted the railing approximately 26 ft (8 m) from the end between posts 4 and 5. Shortly after impact, the right front tire made contact with the lower railing element and began to ride up the curb. As the vehicle continued its forward motion into the railing, the right front tire pushed the lower railing element down. By 0.071 s after impact the cab began to shift to the left, and at approximately 0.109 s the vehicle began to redirect. At 0.149 s the right front tire made contact with post 6, and by 0.276 s the vehicle was airborne. The rear of the vehicle contacted the railing at approximately 0.310 s and began to move parallel to the bridge railing at 0.320 s traveling at 47.5 mi/h (76.4 km/h). The vehicle continued along the top of the railing, and at 0.447 s the lower edge of the box made contact with the top edge of post 8 and began to tear the box as the vehicle continued down the railing still airborne. The vehicle made contact with the ground at about 1.129 s and lost contact with the railing at 1.392 s. Total length of contact with the bridge railing was 74 ft (22.5 m). After the vehicle left the railing, the brakes were applied but the left side of the vehicle made contact with another barrier. The vehicle came to rest 132 ft (40 m) from the point of impact.

Damage to the railing was moderate (figure 38). The bolts connecting the lower railing element to the post were sheared on posts 3 through 7. At post 5 the bolt on the upper railing element was sheared and the face of the element itself was gouged. The flange on post 6 was bent and the concrete curb was cracked at posts 6 through 9. The top of post 8 was bent where it made contact with the box. During the test the lower railing element was pushed down. After the test, the maximum vertical movement was 3 in (76 mm) at post 5.

Damage to the vehicle was extensive. The steering arm rod, u-bolts, spring pins, and front and rear spring mounts were damaged. The frame was bent as well as the rear part of the drive shaft, the rear u-joint, the battery box, and the gas tank. The cargo box was torn during the test and, as the vehicle left the railing and rolled to the right, the load shifted and tore open the right side of the box.

The railing contained and smoothly redirected the vehicle with minimal lateral movement of the railing. There was no intrusion into the occupant compartment and very little deformation of the compartment. The vehicle trajectory at loss of contact indicated minimum intrusion into adjacent traffic lanes, and the vehicle remained relatively stable during the collision.

Performance of the railing in this test is judged acceptable, as indicated in figure 39 and table 12.
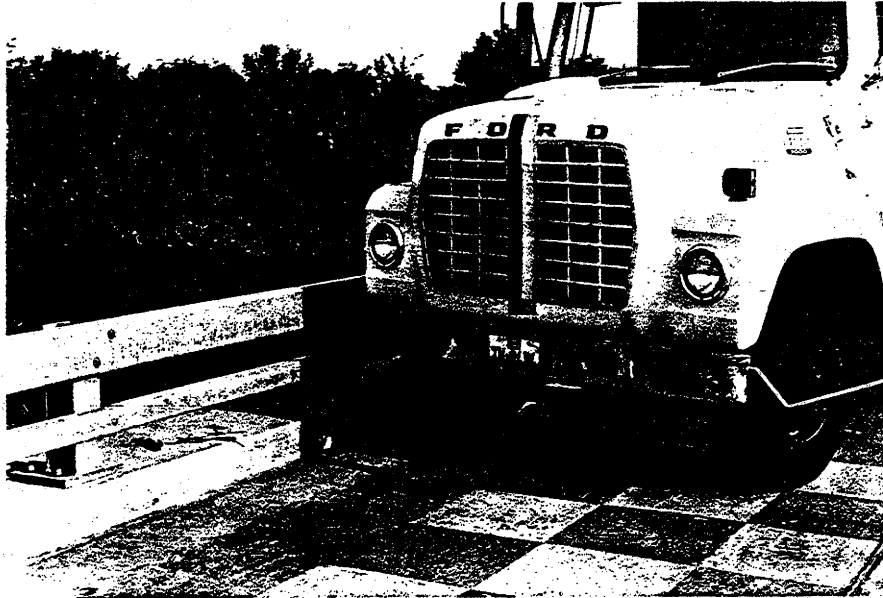
Figure 38. Vehicle and railing for test 7069-15.

| | | 0.000 s | 0.152 s | 0.305 s | 0.508 s |

Test No. . . . . : 7069-15
Date . . . . : 9/13/88
Test Installation . . . . : Illinois 2399-1
                            Bridge Railing
Installation Length . . . : 100 ft (30 m)
Vehicle . . . . : 1980 Ford 7000
                          Single-Unit Truck
Vehicle Weight
  Empty Weight . . . . . : 12,320 lb (5 593 kg)
  Test Inertia . . . . . : 18,000 lb (8 172 kg)
Maximum Vehicle Crush . . : 10.0 in (254 mm)

Impact Speed. . . . . : 50.8 mi/h (81.7 km/h)
Impact Angle. . . . . : 15.1 deg
Exit Speed . . . . . : N/A
Exit Trajectory . . . : 0 deg
Vehicle Accelerations
  (Max. 0.050-sec Avg)
  Longitudinal. . . : -1.9 g
  Lateral . . . . : 4.9 g
Occupant Impact Velocity
  Longitudinal. . . : 9.8 ft/s (3.0 m/s)
  Lateral . . . . : 12.4 ft/s (3.8 m/s)
Occupant Ridedown Accelerations
  Longitudinal. . . : -2.5 g
  Lateral . . . . : 7.4 g

Figure 39. Summary of results for test 7069-15.

1 in = 25.4 mm

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Table 12. Evaluation of crash test no. 7069-15.
{Illinois 2399 Bridge Railing [18,000 lb (8 172 kg)|50.8 mi/h (81.7 km/h)|15.1 degrees]}

	CRITERIA	TEST RESULTS	PASS/FAIL*
A.	Must contain vehicle	Vehicle was contained	Pass
B.	Debris shall not penetrate passenger compartment	No debris penetrated passenger compartment	Pass
C.	Passenger compartment must have essentially no deformation	Acceptable deformation	Pass
D.	Vehicle must remain upright	Vehicle remained upright	Pass
E.	Must smoothly redirect the vehicle	Vehicle was smoothly redirected	Pass
F.	Effective coefficient of friction μ — Assessment 0 - .25 — Good .26 - .35 — Fair > .35 — Marginal	μ — Assessment 0.12 — Good	Pass
G.	Shall be less than Occupant Impact Velocity - ft/s (m/s) Longitudinal — Lateral 30 (9.2) — 25 (7.6) Occupant Ridedown Accelerations - g's Longitudinal — Lateral 15 — 15	Occupant Impact Velocity - ft/s (m/s) Longitudinal — Lateral 9.8 (3.0) — 12.4 (3.8) Occupant Ridedown Accelerations - g's Longitudinal — Lateral -2.5 — 7.4	N/A N/A
H.	Exit angle shall be less than 12 degrees	Exit angle was about 0 degrees	Pass

* A, B, C, are required. D, E, F, and H are desired. G is not applicable for this test. (See table 1)

80

32-in (813-mm) Parapet

Test Number 7069-5

Vehicle:	1981 Honda
Test Inertia Weight:	1,800 lb (817 kg)
Gross Static Weight:	1,965 lb (892 kg)
Impact Speed:	60.5 mi/h (97.3 km/h)
Impact Angle:	21.0 deg

The vehicle impacted the parapet at midlength. At approximately 0.023 s after impact, the right front tire impacted the parapet and began to redirect after 0.062 s. The rear of the vehicle hit the parapet at 0.157 s and was parallel to the parapet at 0.162 s. The vehicle lost contact with the parapet at 0.236 s after impact. As the vehicle exited the parapet, it had a yaw angle of 3.5 degrees and trajectory path of 6.2 degrees. The vehicle brakes were then applied, and the vehicle came to rest 167 ft (51 m) downstream and 26 ft (8 m) toward the field side of the point of impact.

The parapet received cosmetic damage only (figure 40). There were tire marks on the face of the parapet. The vehicle was in contact with the parapet for 10.3 ft (3.1 m).

The vehicle sustained extensive damage to the right front as shown in figure 40. Maximum crush at the right front corner at bumper height was 5.0 in (127 mm). The right front and right rear wheel rims were bent, and the right front strut was bent. The passenger door was bent and jammed, and the right side was dented and scraped. The hood was bent and shifted to the left. The windshield frame was bent, and the windshield was cracked. The roof of the vehicle was buckled and twisted.

The parapet contained and smoothly redirected the vehicle with no lateral movement of the parapet. There were no debris or detached elements. There was no intrusion into the occupant compartment although some deformation of the compartment occurred. The vehicle trajectory at loss of contact indicated minimum intrusion into adjacent traffic lanes. The vehicle remained upright and stable during the entire test period.

The lateral occupant impact velocity of 26.0 ft/s (7.9 m/s) is higher than the maximum acceptable value of 25 ft/s (7.6 m/s). However, the authors conclude that the performance of this parapet in this test is acceptable on the basis of two arguments. The value obtained is marginally close to being acceptable. The acceptable value was selected as a reasonably achievable value for impact angles of 15 degrees, not the more severe condition of 20 degrees used in this test. See figure 41 and table 13.
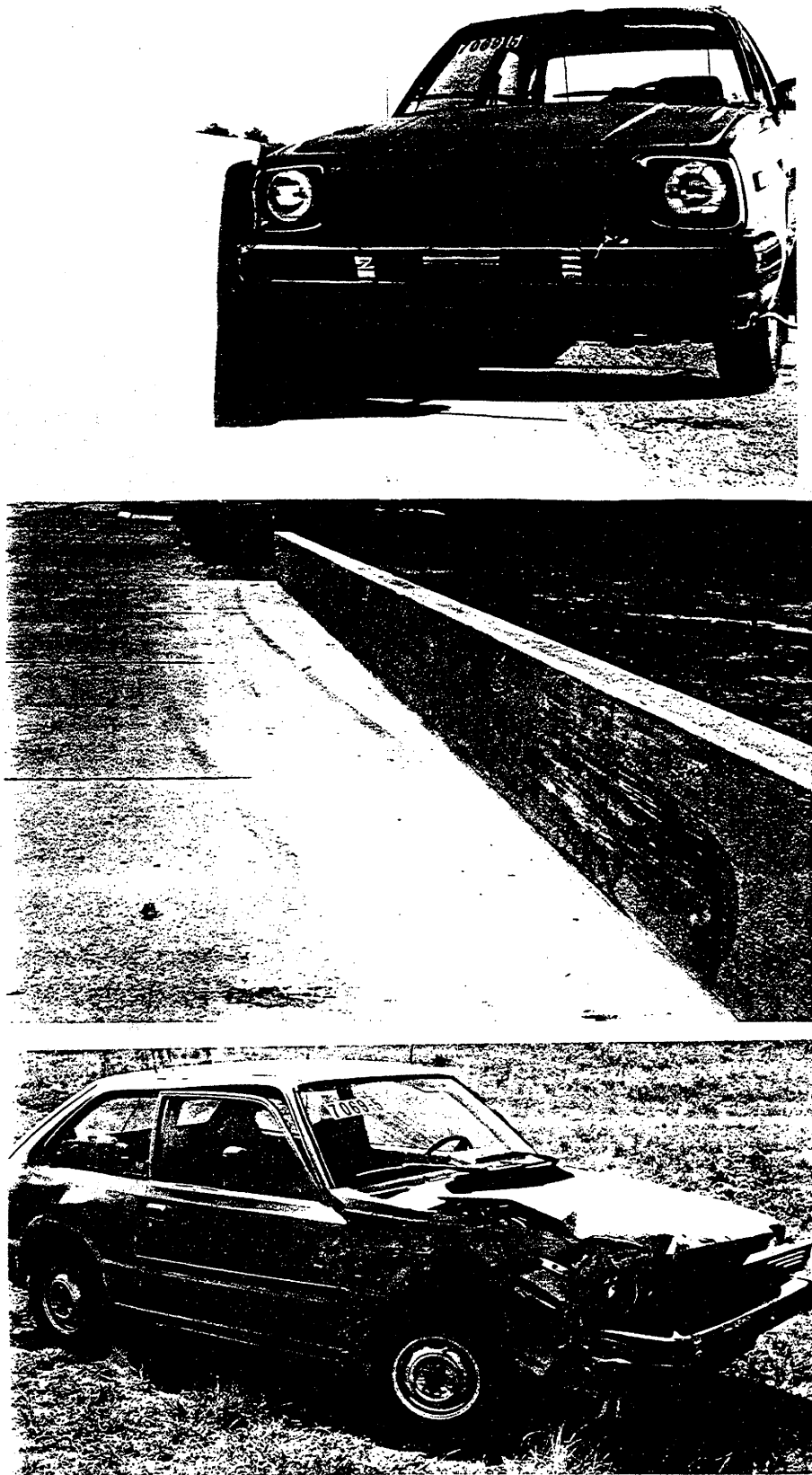
Figure 40. Vehicle and parapet for test 7069-5.

Test No.	.	7069-5
Date	.	9/24/87
Test Installation . . .	.	32-in (813-mm)
		Concrete Parapet
Installation Length . .	.	100 ft (30 m)
Vehicle	.	1981 Honda
		Civic
Vehicle Weight		
Test Inertia	.	1,800 lb (817 kg)
Gross Static	.	1,965 lb (892 kg)
Vehicle Damage Classification		
TAD	.	01RFQ4
CDC	.	01FREK2 & 01RYEW3
Maximum Vehicle Crush .	.	5.0 in (127 mm)

Impact Speed. . .	.	60.5 mi/h (97.3 km/h)
Impact Angle. . .	.	21.0 deg
Exit Speed. . . .	.	48.6 mi/h (78.2 km/h)
Exit Trajectory .	.	6.2 deg
Vehicle Accelerations		
(Max. 0.050-sec Avg)		
Longitudinal. .	.	-8.0 g
Lateral . . .	.	14.0 g
Occupant Impact Velocity		
Longitudinal. .	.	20.1 ft/s (6.1 m/s)
Lateral . . .	.	26.0 ft/s (7.9 m/s)
Occupant Ridedown Accelerations		
Longitudinal. .	.	-1.6 g
Lateral . . .	.	9.4 g

1 in = 25.4 mm

Figure 41. Summary of results for test 7069-5.

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Table 13. Evaluation of crash test no. 7069-5.
{32-in (813-mm) Concrete Parapet Bridge Railing [1,800 lb (817 kg)|60.5 mi/h (97.3 km/h)|21.0 degrees]}

	CRITERIA	TEST RESULTS	PASS/FAIL*
A.	Must contain vehicle	Vehicle was contained	Pass
B.	Debris shall not penetrate passenger compartment	No debris penetrated passenger compartment	Pass
C.	Passenger compartment must have essentially no deformation	Acceptable deformation	Pass
D.	Vehicle must remain upright	Vehicle remained upright	Pass
E.	Must smoothly redirect the vehicle	Vehicle was smoothly redirected	Pass
F.	Effective coefficient of friction _μ_ Assessment 0 - .25 Good .26 - .35 Fair > .35 Marginal	_μ_ Assessment .22 Good	Pass
G.	Shall be less than		
	Occupant Impact Velocity - ft/s (m/s) Longitudinal Lateral 30 (9.2) 25 (7.6)	Occupant Impact Velocity - ft/s (m/s) Longitudinal Lateral 20.1 (6.1) 26.0 (7.9)	Fail (see discussion)
	Occupant Ridedown Accelerations - g's Longitudinal Lateral 15 15	Occupant Ridedown Accelerations - g's Longitudinal Lateral -1.6 9.4	Pass
H.	Exit angle shall be less than 12 degrees	Exit angle was 6.2 degrees	Pass

* A, B, C, D and G are required. E, F, and H are desired. (See table 1)

<u>Test Number 7069-6</u>

Vehicle: 1982 Chevrolet Pickup
Test Inertia Weight: 5,420 lb (2 461 kg)
Gross Static Weight: 5,759 lb (2 615 kg)
Impact Speed: 59.7 mi/h (96.1 km/h)
Impact Angle: 20.2 deg

The vehicle impacted the parapet at midlength. At approximately 0.021 s after impact, the right front wheel contacted the parapet. The vehicle began to redirect at 0.074 s as the rear end began to slide toward the parapet. The dummies began to move abruptly to the right at 0.080 s, and 0.130 s, the passenger dummy's head shattered the right side window glass. The rear of the vehicle slapped the parapet at 0.192 s, and by 0.209 s, the vehicle was traveling parallel to the parapet. The vehicle lost contact with the parapet at 0.418 s. It was in contact with the parapet for 10.5 ft (3.2 m). The vehicle exited the parapet with a yaw angle of 5.6 degrees and a vehicle trajectory path of 6.4 degrees. The brakes were applied, and the vehicle came to rest 225 ft (69 m) downstream and 40 ft (12 m) toward the field side of the point of impact.

The parapet received only cosmetic damage as shown in figure 42. There were tire marks on the face of the parapet.

The vehicle sustained extensive damage to the right side (figure 42). Maximum crush at the right front corner at bumper height was 9.0 in (229 mm). The right front and right rear wheel rims were bent, and the welds had broken on the right front wheel rim, allowing the outer rim and tire to become completely separated. The wheel assembly and suspension were damaged. The passenger door was bent and jammed, and the window was broken. The right rear panel was dented and scraped. The hood was bent and shifted to the left. The cab of the vehicle was twisted, and the frame was bent.

The parapet contained and smoothly redirected the vehicle with minimal lateral movement of the parapet. There were no debris or detached elements. There was no intrusion into the occupant compartment although some deformation of the right door occurred. The vehicle trajectory at loss of contact indicated minimum intrusion into adjacent traffic lanes. The vehicle remained upright and stable during the entire test period.

Performance of the parapet in this test is judged acceptable, as indicated figure 43 and table 14.

Figure 42. Vehicle and parapet for test 7069-6.

| | 0.000 s | 0.130 s | 0.250 s | 0.380 s |
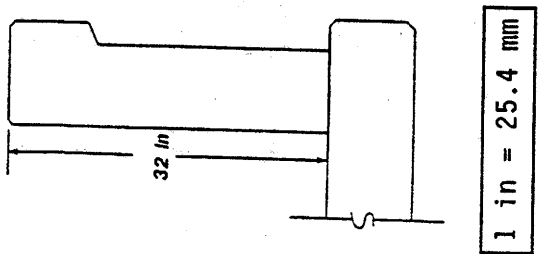
Test No. . . . . : 7069-6
Date . . . . : 10/08/87
Test Installation . . . . : 32-in (813-mm)
                            Concrete Parapet
Installation Length . . . : 100 ft (30 m)
Vehicle . . . . : 1982 Chevrolet
                            Pickup
Vehicle Weight
    Test Inertia . . . . . : 5,420 lb (2 461 kg)
    Gross Static . . . . . : 5,759 lb (2 615 kg)
Vehicle Damage Classification
    TAD . . . . : 01RD4
    CDC . . . . : 01FREK2 & 01RYEW4
Maximum Vehicle Crush . . : 9.0 in (229 mm)

Impact Speed. . . . . : 59.7 mi/h (96.1 km/h)
Impact Angle. . . . . : 20.2 deg
Exit Speed. . . . . . : 47.0 mi/h (75.6 km/h)
Exit Trajectory . . . : 6.4 deg
Vehicle Accelerations
    (Max. 0.050-sec Avg)
    Longitudinal. . . : -5.7 g
    Lateral . . . . . : 13.1 g
Occupant Impact Velocity
    Longitudinal. . . : 18.6 ft/s (5.7 m/s)
    Lateral . . . . . : 21.1 ft/s (6.4 m/s)
Occupant Ridedown Accelerations
    Longitudinal. . . : -5.5 g
    Lateral . . . . . : 8.6 g

Figure 43. Summary of results for test 7069-6.

32 in

1 in = 25.4 mm

87

Table 14. Evaluation of crash test no. 7069-6.
{32-in (813-mm) Concrete Parapet Bridge Railing [5,420 lb (2 461 kg)|59.7 mi/h (96.1 km/h)|20.2 degrees]}

	CRITERIA	TEST RESULTS	PASS/FAIL*
A.	Must contain vehicle	Vehicle was contained	Pass
B.	Debris shall not penetrate passenger compartment	No debris penetrated passenger compartment	Pass
C.	Passenger compartment must have essentially no deformation	Acceptable deformation	Pass
D.	Vehicle must remain upright	Vehicle remained upright	Pass
E.	Must smoothly redirect the vehicle	Vehicle was smoothly redirected	Pass
F.	Effective coefficient of friction $\underline{\mu}$ $\underline{Assessment}$ 0 - .25 Good .26 - .35 Fair > .35 Marginal	$\underline{\mu}$ $\underline{Assessment}$ .32 Good	Pass
G.	Shall be less than Occupant Impact Velocity - ft/s (m/s) Longitudinal Lateral 30 (9.2) 25 (7.6) Occupant Ridedown Accelerations - g's Longitudinal Lateral 15 15	Occupant Impact Velocity - ft/s (m/s) Longitudinal Lateral 18.6 (5.7) 21.1 (6.4) Occupant Ridedown Accelerations - g's Longitudinal Lateral -5.5 8.6	Pass Pass
H.	Exit angle shall be less than 12 degrees	Exit angle was 6.4 degrees	Pass

* A, B, C, and D are required. E, F, G, and H are desired. (See table 1)

88

<u>Test Number 7069-16</u>

Vehicle:	1982 Ford Single-Unit Truck
Test Inertia Weight:	18,000 lb (8 172 kg)
Empty Weight:	13,820 lb (6 274 kg)
Impact Speed:	50.0 mi/h (80.5 km/h)
Impact Angle:	14.0 deg

The vehicle impacted the parapet approximately 20 ft (6 m) from the end. Shortly after impact, the right front wheel made contact with the parapet and was pushed back and to the left. The vehicle began to redirect at approximately 0.101 s after impact. At 0.263 s, the left side of the vehicle became airborne. The rear of the vehicle impacted the parapet at about 0.305 s and began to travel parallel to the parapet. As the vehicle rode along the parapet, it continued to roll to the right and attained a maximum roll angle of 17.6 degrees at 0.480 s. At about 0.750 s, the vehicle began to right itself. It lost contact with the parapet at 0.963 s, traveling at 34.2 mi/h (55.0 km/h) and 5.0 degrees. It was in contact with the parapet for about 45 ft (14 m). By 1.101 s, the vehicle was traveling upright; however, it continued to roll to the left and began to yaw clockwise. The vehicle came to rest on its left side 175 ft (53 m) downstream and 25 ft (7.6 m) toward the field side of the point of impact.

The parapet received only cosmetic damage (figure 44). There were tire marks on the face of the parapet and along the top for about 30 ft (9 m). The bed of the vehicle scraped the top of the parapet for another 15 ft (4.6 m).

The vehicle sustained moderate damage to the right side (figure 44). Maximum crush at the right front corner at bumper height was 10.0 in (254 mm). The front bumper, the hood, and the right front quarter were damaged, and the windshield was cracked. The rear U-bolt on the right front springs was broken, and the springs were dislocated. The fuel tank and straps were also damaged.

The parapet contained and smoothly redirected the vehicle with no lateral movement of the parapet. There was no intrusion into the occupant compartment and very little deformation of the compartment. The vehicle trajectory at loss of contact indicated minimum intrusion into adjacent traffic lanes.

Performance of the parapet in this test is judged acceptable, as indicated in figure 45 and table 15.
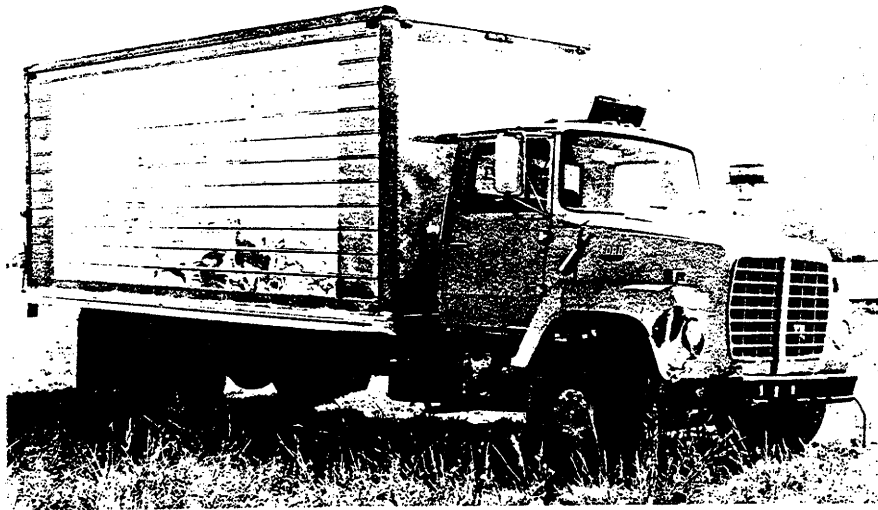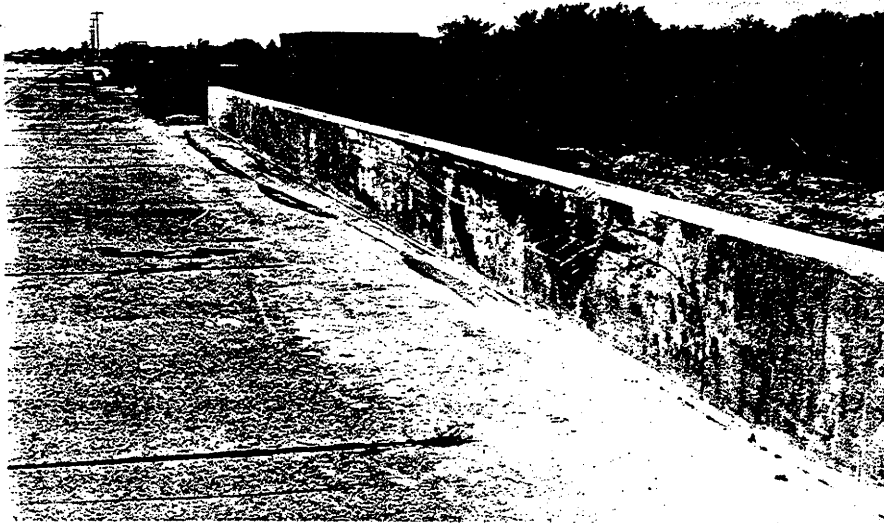
Figure 44. Vehicle and parapet for test 7069-16.

90

0.000 s 0.172 s 0.368 s 0.613 s
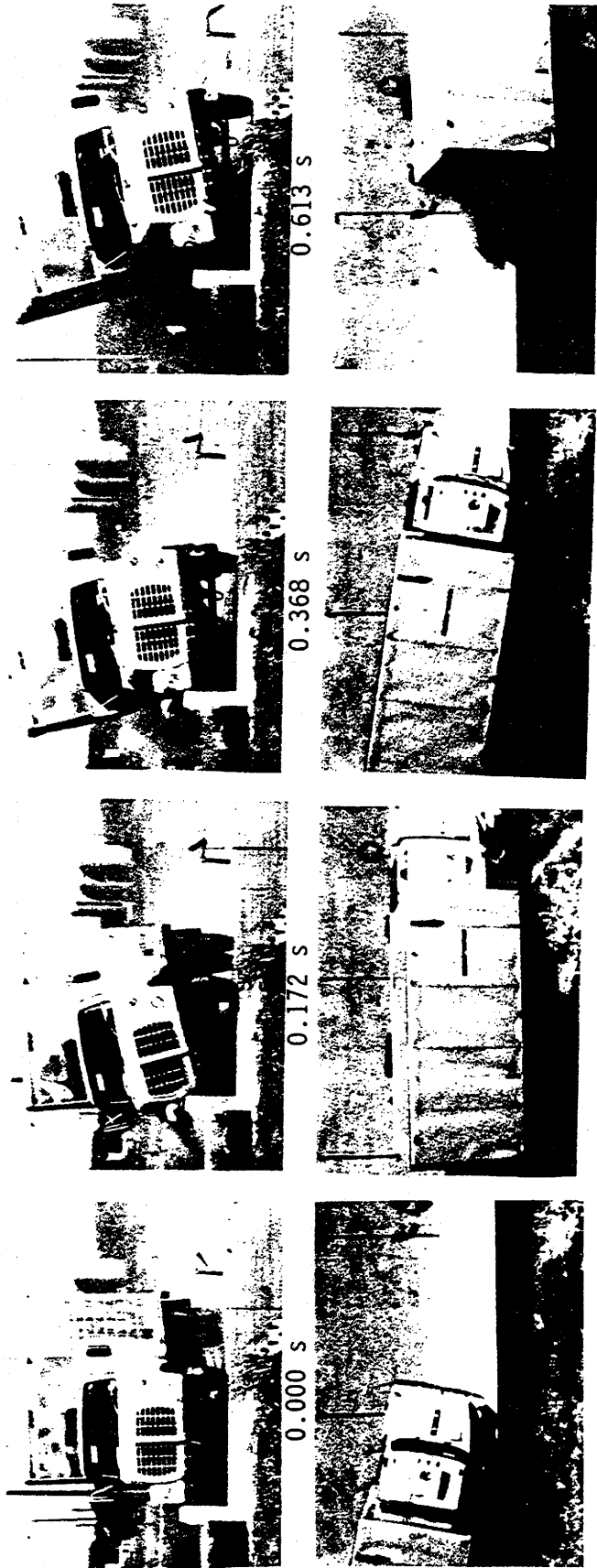
Test No.	7069-16
Date	10/13/88
Test Installation	32-in (813-mm)
	Concrete Parapet
Installation Length	100 ft (30.5 cm)
Vehicle	1982 Ford 7000
	Single-Unit Truck
Vehicle Weight	
Empty Weight	13,820 lb (6 274 kg)
Test Inertia	18,000 lb (8 172 kg)
Maximum Vehicle Crush	10.0 in (254 mm)

Impact Speed	50.0 mi/h (80.5 km/h)
Impact Angle	14.0 deg
Exit Speed	34.2 (55.0 km/h)
Exit Trajectory	5 deg
Vehicle Accelerations	
(Max. 0.050-sec Avg)	
Longitudinal	-1.7 g
Lateral	4.6 g
Occupant Impact Velocity	
Longitudinal	10.9 ft/s (3.3 m/s)
Lateral	11.8 ft/s (3.6 m/s)
Occupant Ridedown Accelerations	
Longitudinal	-2.3 g
Lateral	8.4 g
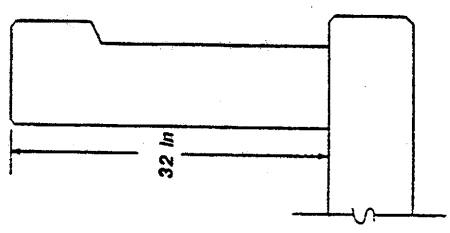
32 In

1 in = 25.4 mm

Figure 45. Summary of results for test 7069-16.

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Table 15. Evaluation of crash test no. 7069-16.
{32-in (813-mm) Concrete Parapet [18,000 lb (8 172 kg)|50 mi/h (80.5 km/h)|14.0 degrees]}

	CRITERIA	TEST RESULTS	PASS/FAIL*
A.	Must contain vehicle	Vehicle was contained	Pass
B.	Debris shall not penetrate passenger compartment	No debris penetrated passenger compartment	Pass
C.	Passenger compartment must have essentially no deformation	Acceptable deformation	Pass
D.	Vehicle must remain upright	Vehicle did not remain upright	Pass
E.	Must smoothly redirect the vehicle	Vehicle was smoothly redirected	Pass
F.	Effective coefficient of friction $\underline{\mu}$ — $\underline{Assessment}$ 0 – .25 — Good .26 – .35 — Fair > .35 — Marginal	$\underline{\mu}$ — $\underline{Assessment}$ 0.41 — Marginal	Pass
G.	Shall be less than		
	Occupant Impact Velocity - ft/s (m/s) Longitudinal — Lateral 30 (9.2) — 25 (7.6)	Occupant Impact Velocity - ft/s (m/s) Longitudinal — Lateral 10.9 (3.3) — 11.8 (3.6)	N/A
	Occupant Ridedown Accelerations - g's Longitudinal — Lateral 15 — 15	Occupant Ridedown Accelerations - g's Longitudinal — Lateral -2.3 — 8.4	N/A
H.	Exit angle shall be less than 12 degrees	Exit angle was 5 degrees	Pass

*A, B, and C are required. D, E, F, and H are desired. G is not applicable for this test. (See table 1)

32-in (813-mm) New Jersey Safety Shape

Test Number 7069-12

Vehicle:	1982 GMC Single-Unit Truck
Test Inertia Weight:	18,000 lb (8 172 kg)
Empty Weight:	10,900 lb (4 949 kg)
Impact Speed:	51.6 mi/h (83.0 km/h)
Impact Angle:	15.5 deg

The vehicle impacted the safety shape approximately 23 ft (7 m) from the end. Shortly after impact, the right front wheel began to ride up the face of the safety shape. At 0.093 s, the axle broke on the right side, and the left front tire became airborne. The vehicle began to slowly redirect as the rear end began to slide toward the safety shape. The lower edge of the front bumper reached the top of the safety shape at 0.101 s. At 0.312 s, the left rear wheels became airborne, and the front of the vehicle reached a maximum height of approximately 1 ft (.03 m) above the safety shape. As the vehicle rode along the top of the safety shape, it continued to roll to the right and reached maximum redirection at 0.324 s at an angle of 8.6 degrees into the safety shape. At about 0.627 s, the front of the vehicle extended over the safety shape by one-half the vehicle's width. By 1.040 s, the vehicle attained a maximum roll angle of 44 degrees to the right and began to right itself. As the vehicle slid off the end of the safety shape, it continued to roll to the left (away from the railing). The vehicle subsequently came to rest on its left side 75 ft (23 m) from the end of the safety shape.

The safety shape received only cosmetic damage and some scraping and gouging (figure 46). There were tire marks on the face and top of the safety shape. The top of the safety shape was scraped along the remaining length by the undercarriage of the truck.

The vehicle sustained extensive damage to the right side. Maximum crush at the right front corner at bumper height was 8.0 in (203 mm). The front axle was torn off the vehicle, and the undercarriage damaged. There was damage to the U-bolts, Pittman arm rod, steering arm, brake lines, and leaf spring bolts. The outer right rear wheel rim and tire were damaged. The fuel tank also sustained damage.

The safety shape contained and redirected the vehicle with no lateral movement of the safety shape. There was no intrusion into the occupant compartment and very little deformation of the compartment. The vehicle trajectory at loss of contact indicated minimum intrusion into adjacent traffic lanes; however,the vehicle did not remain upright after collision.

Performance of the safety shape in this test is judged acceptable, as indicated in figure 47 and table 16.

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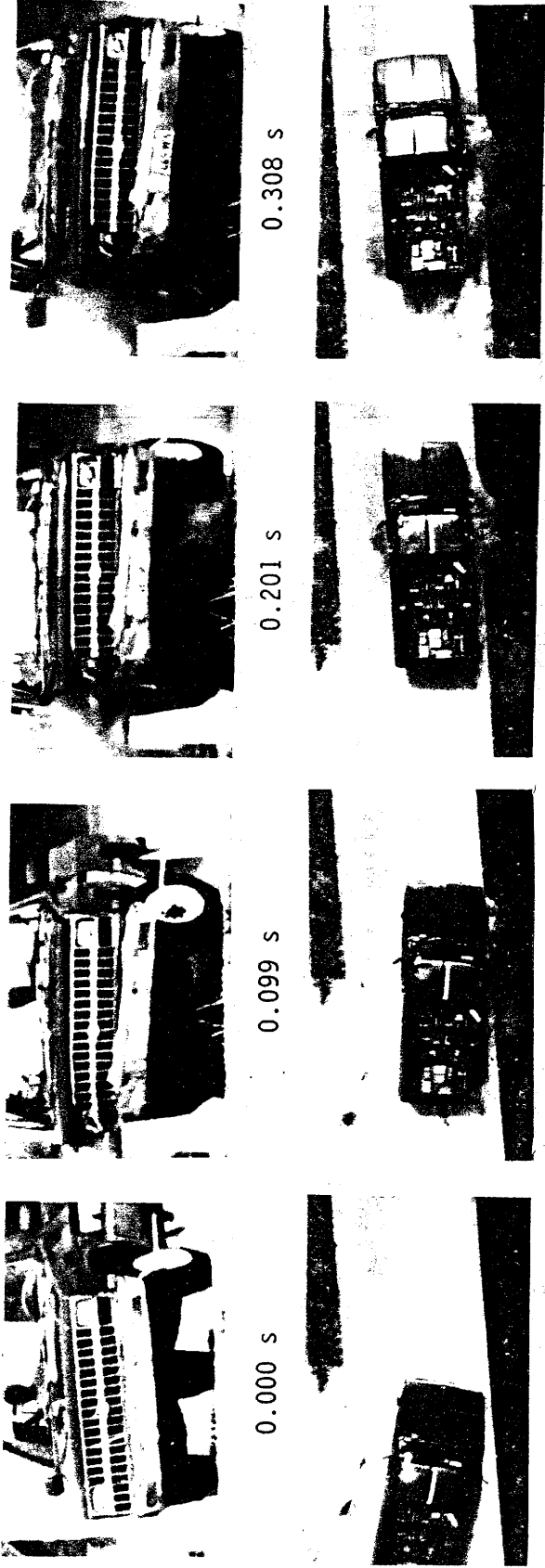Figure 46. Vehicle and safety shape for test 7069-12.

Test No.	7069-12
Date	6/22/88
Test Installation . . .	32-in (813-mm) New Jersey Safety Shape Bridge Railing
Installation Length. . .	100 ft (30 m)
Vehicle	1982 GMC Single-Unit Truck
Vehicle Weight	
Empty Weight	10,900 lb (4 949 kg)
Test Inertia	18,000 lb (8 172 kg)
Maximum Vehicle Crush .	8.0 in (203 mm)

Impact Speed. . .	51.6 mi/h (83.0 km/h)
Impact Angle. . .	15.5 deg
Exit Speed. . . .	N/A
Exit Trajectory .	2.0 deg
Vehicle Accelerations	
(Max. 0.050-sec Avg)	
Longitudinal. .	-3.2 g
Lateral . . .	2.5 g
Occupant Impact Velocity	
Longitudinal. .	13.4 ft/s (4.1 m/s)
Lateral	10.2 ft/s (3.1 m/s)
Occupant Ridedown Accelerations	
Longitudinal. .	-3.0 g
Lateral	4.9 g

Figure 47. Summary of results for test 7069-12.

1 in = 25.4 mm

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Table 16. Evaluation of crash test no. 7069-12.

{32-in (813-mm) New Jersey Safety Shape [18,000 lb (2 172 kg)|51.6 mi/h (83.0 km/h)|15.5 degrees]}

	CRITERIA	TEST RESULTS	PASS/FAIL
A.	Must contain vehicle	Vehicle was contained	Pass
B.	Debris shall not penetrate passenger compartment	No debris penetrated passenger compartment	Pass
C.	Passenger compartment must have essentially no deformation	Acceptable deformation	Pass
D.	Vehicle must remain upright	Vehicle did not remain upright	Fail
E.	Must smoothly redirect the vehicle	Vehicle was smoothly redirected	Pass
F.	Effective coefficient of friction μ Assessment 0 - .25 Good .26 - .35 Fair > .35 Marginal	μ Assessment N/A	N/A
G.	Shall be less than Occupant Impact Velocity - ft/s (m/s) Longitudinal Lateral 30 (9.2) 25 (7.6) Occupant Ridedown Accelerations - g's Longitudinal Lateral 15 15	Occupant Impact Velocity - ft/s (m/s) Longitudinal Lateral 13.4 (4.1) 10.2 (3.1) Occupant Ridedown Accelerations - g's Longitudinal Lateral -3.0 4.9	N/A N/A
H.	Exit angle shall be less than 12 degrees	about 2 degrees	Pass

* A, B, C are required. D, E, F, and H are desired. G is not applicable for this test. (see table 1)

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Test Number 7069-14

Vehicle: 1981 Chevrolet Pickup
Test Inertia Weight: 5,390 lb (2 447 kg)
Gross Static Weight: 5,724 lb (2 599 kg)
Impact Speed: 57.7 mi/h (92.8 km/h)
Impact Angle: 20.6 deg

The vehicle impacted the safety shape approximately 11 ft (3.4 m) from the upstream end. Shortly after impact, the right front wheel began to ride up the face of the safety shape. At 0.060 s, the dummies began to move to the right. The vehicle began to redirect at 0.103 s, and the left front tire became airborne at 0.195 s. By 0.241 s, the vehicle was traveling parallel to the safety shape at a speed of 37.1 mi/h. At 0.356 s, the vehicle became completely airborne, and the front of the vehicle reached a maximum height of approximately 23 in (58.9 m) above the bridge deck. While still airborne, the vehicle lost contact with the safety shape at 0.365 s traveling at 35.8 mi/h and 0.9 degrees. It was in contact with the safety shape for 15 ft (4.6 m). The vehicle's left front wheel touched ground at 0.532 s after impact. The brakes were then applied, and the vehicle yawed clockwise and came to rest 280 ft (85 m) from the point of impact.

The safety shape received only cosmetic damage (figure 48). There were tire marks on the face and top of the safety shape.

The vehicle sustained extensive damage to the right side (figure 48). Maximum crush at the right front corner at bumper height was 12.0 in (307 mm). The right front suspension system broke away from the vehicle, and the right rear tire and wheel rim broke at the welded connection points. There was damage to the right ball joints and tie rods, as well as the upper and lower control arms. The left rear tire was deflated.

The safety shape contained and smoothly redirected the vehicle with no lateral movement of the safety shape. There was no intrusion into the occupant compartment and minimal deformation of the compartment. The vehicle trajectory at loss of contact indicated minimum intrusion into adjacent traffic lanes. The vehicle remained upright and relatively stable during the collision.

Performance of the safety shape in this test is judged acceptable, as indicated in figure 49 and table 17.
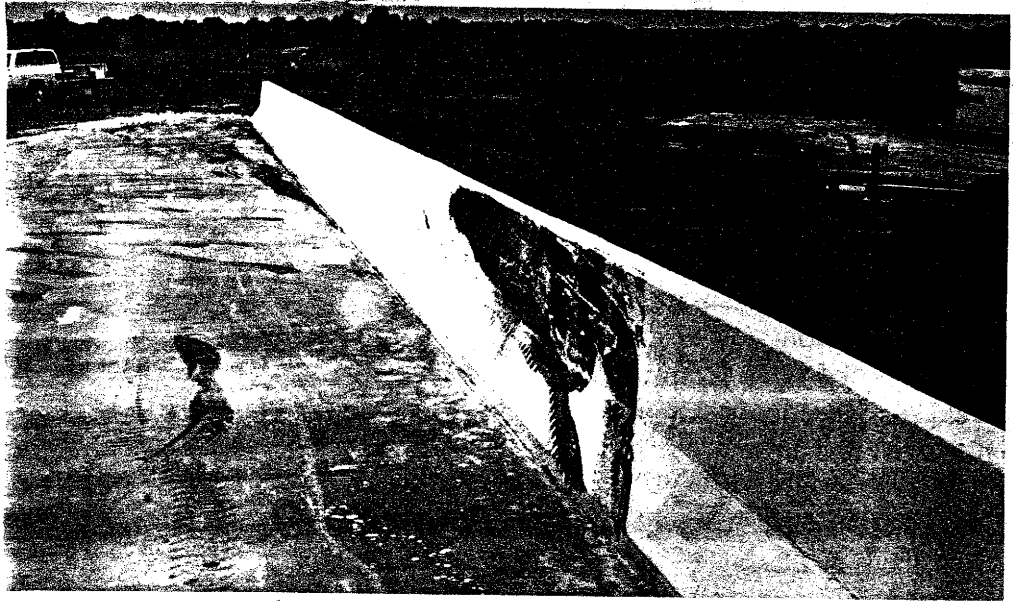
Figure 48. Vehicle and safety shape for test 7069-14.

0.000 s	0.101 s
0.201 s	0.377 s
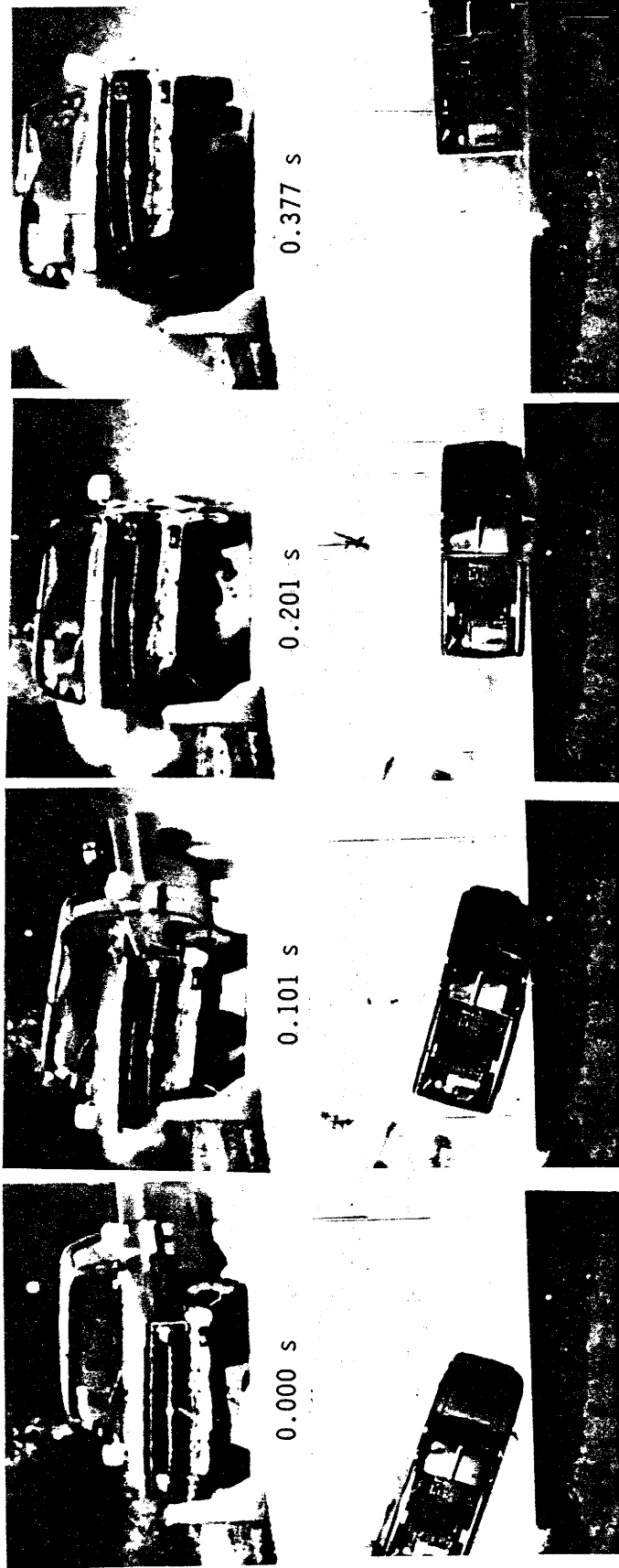
Test No. . . . . : 7069-14
Date . . . . : 8/11/88
Test Installation . . . : 32-in (813-mm)
    New Jersey Safety Shape Bridge Railing
Installation Length . . : 100 ft (30 m)
Vehicle . . . . . : 1981 Chevrolet Custom
    Deluxe C-20 Pickup
Vehicle Weight
    Test Inertia . . . . : 5,390 lb (2 447 kg)
    Gross Static . . . . : 5,724 lb (2 599 kg)
Vehicle Damage Classification
    TAD . . . . : 01RFQ5
    CDC . . . . : 01FREK3 & 01RYEW4
Maximum Vehicle Crush . : 12.0 in (307 mm)

Impact Speed. . . . . . : 57.7 mi/h (92.8 km/h)
Impact Angle. . . . . . : 20.6 deg
Exit Speed. . . . . . . : 35.8 mi/h (57.6 km/h)
Exit Trajectory . . . . : 0.9 deg
Vehicle Accelerations
    (Max. 0.050-sec Avg)
    Longitudinal. . . . : -6.6 g
    Lateral . . . . . . : 7.3 g
Occupant Impact Velocity
    Longitudinal. . . . : 17.8 ft/s (5.4 m/s)
    Lateral . . . . . . : 18.7 ft/s (5.7 m/s)
Occupant Ridedown Accelerations
    Longitudinal. . . . : -5.1 g
    Lateral . . . . . . : 9.2 g
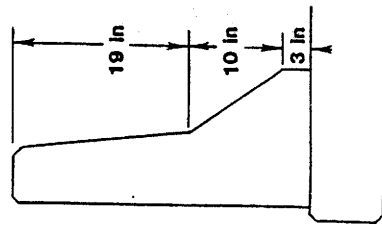
Figure 49. Summary of results for test 7069-14.

1 in = 25.4 mm

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Table 17. Evaluation of crash test no. 7069-14.
{32-in (813-mm) New Jersey Safety Shape [5,390 lb (2 447 kg)|57.7 mi/h (92.8 km/h)|20.6 degrees]}

	CRITERIA	TEST RESULTS	PASS/FAIL*
A.	Must contain vehicle	Vehicle was contained	Pass
B.	Debris shall not penetrate passenger compartment	No debris penetrated passenger compartment	Pass
C.	Passenger compartment must have essentially no deformation	Acceptable deformation	Pass
D.	Vehicle must remain upright	Vehicle did remain upright	Pass
E.	Must smoothly redirect the vehicle	Vehicle was smoothly redirected	Pass
F.	Effective coefficient of friction		
	μ Assessment 0 - .25 Good .26 - .35 Fair > .35 Marginal	μ Assessment 0.83 Marginal	Pass
G.	Shall be less than		
	Occupant Impact Velocity - ft/s (m/s) Longitudinal Lateral N/A N/A	Occupant Impact Velocity - ft/s (m/s) Longitudinal Lateral 17.8 (5.4) 18.7 (5.7)	N/A
	Occupant Ridedown Accelerations - g's Longitudinal Lateral N/A N/A	Occupant Ridedown Accelerations - g's Longitudinal Lateral -5.1 9.2	N/A
H.	Exit angle shall be less than 12 degrees	about 0.9 degrees	Pass

* A, B, C, and D are required. E, F, G, and H are desired. (See table 1)

100

32-in (813-mm) F-Shape

Test Number 7069-3

Vehicle:	1980 Honda
Test Inertia Weight:	1,800 lb (817 kg)
Gross Static Weight:	1,966 lb (893 kg)
Impact Speed:	60.1 mi/h (96.7 km/h)
Impact Angle:	21.4 deg

The vehicle impacted the bridge railing at midlength. At approximately 0.025 s after impact the right front tire began to ride up the concrete face of the bridge railing, and by 0.034 s the vehicle began to redirect. As the vehicle continued forward, the right side of the vehicle continued to ride up the face of the bridge railing, and at 0.186 s the left front wheel left the ground. The rear of the vehicle hit the railing at 0.189 s, and at 0.271 s the vehicle was parallel with the railing. The vehicle was in contact with the railing for 10.3 ft (3.1 m). It lost contact with the railing at 0.276 s after impact. As the vehicle exited the railing, it had a yaw angle of 0.9 degree and a trajectory path of 6.2 degrees. The vehicle brakes were applied and the vehicle subsequently came to rest 209 ft (64 m) downstream and 27 ft (8 m) toward the field side of the point of impact.

The railing received cosmetic damage only (figure 50). There were tire marks on the face of the bridge railing indicating the vehicle rose a maximum height of about 27 in (610 mm).

The vehicle sustained extensive damage to the right front corner (figure 50). Maximum crush at the right front corner at bumper height was 9.0 in (229 mm). The right front and right rear wheel rims were bent and the wheel assembly and suspension damaged. The passenger door was bent and jammed and the right side was dented and scraped. The hood was bent and shifted to the left. The windshield frame was bent and the windshield was cracked. The roof of the vehicle was buckled and twisted.

The railing contained and smoothly redirected the vehicle with no lateral movement of the railing. There were no debris or detached elements. There was no intrusion into the occupant compartment although some deformation of the compartment occurred. The vehicle trajectory at loss of contact indicated minimum intrusion into adjacent traffic lanes. The vehicle remained upright and stable during the entire test period.

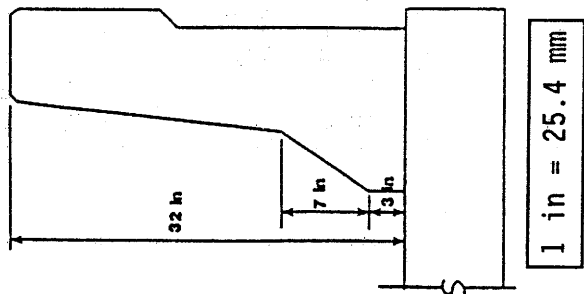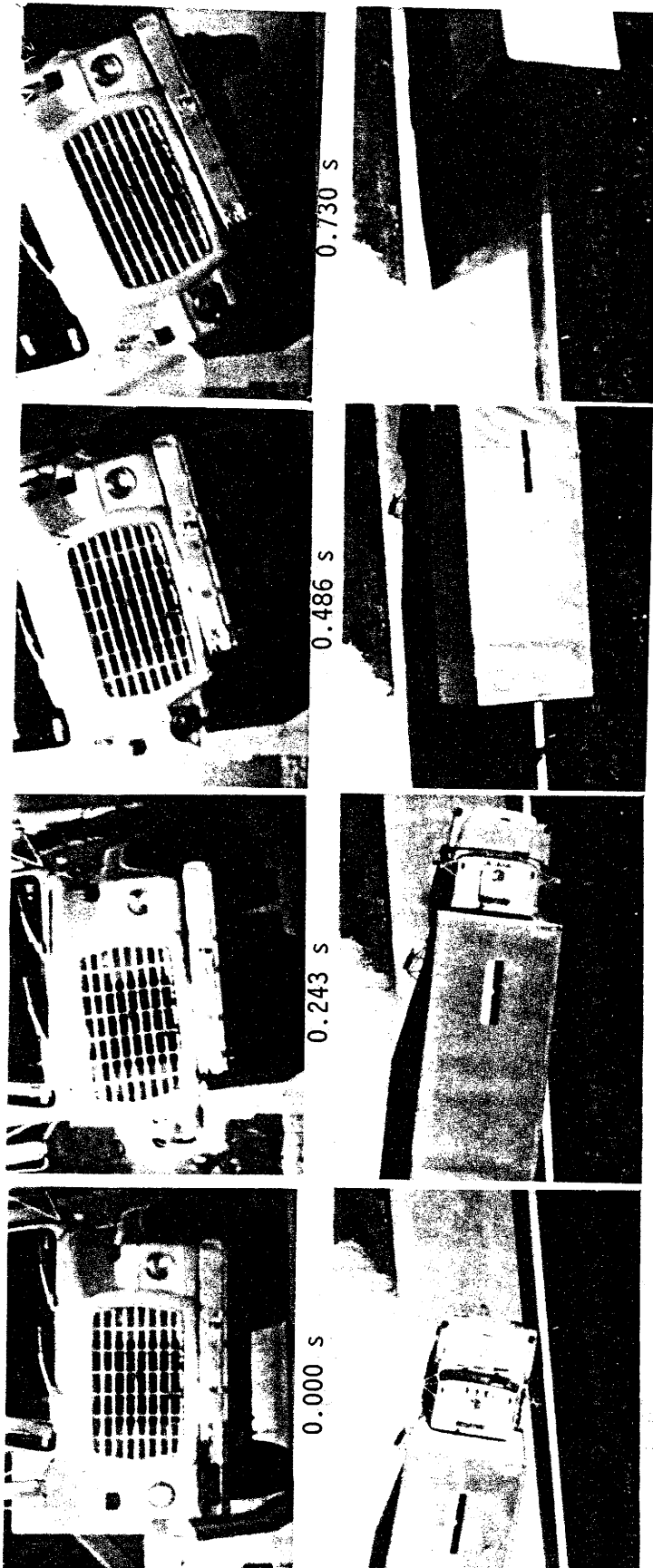Performance of the railing in this test is judge acceptable, as indicated in figure 51 and table 18.

Figure 50. Vehicle and F-shape for test 7069-3.

0.000 s	0.101 s	0.210 s	0.302 s

Test No. 7069-3
Date 7/28/87
Test Installation 32-in (813-mm)
                            F-shape Bridge Railing
Installation Length . . . 100 ft (30 m)
Vehicle . . . . 1980 Honda
                            1300 DX
Vehicle Weight
    Test Inertia . . . . . 1,800 lb (817 kg)
    Gross Static . . . . . 1,966 lb (893 kg)
Vehicle Damage Classification
    TAD 01RFQ4
    CDC . . . . 01FREK3 & 01RFEW4
Maximum Vehicle Crush . 9.0 in (229 mm)

Impact Speed. . . . 60.1 mi/h (96.7 km/h)
Impact Angle. . . . 21.4 deg
Exit Speed. . . . . 53.0 mi/h (85.3 km/h)
Exit Trajectory . . 6.2 deg
Vehicle Accelerations
    (Max. 0.050-sec Avg)
    Longitudinal. . -8.0 g
    Lateral . . . . 12.8 g
Occupant Impact Velocity
    Longitudinal. . 19.0 ft/s (5.8 m/s)
    Lateral . . . . 23.7 ft/s (7.2 m/s)
Occupant Ridedown Accelerations
    Longitudinal. . -2.1 g
    Lateral . . . . 4.9 g

Figure 51. Summary of results for test 7069-3.

1 in = 25.4 mm

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Table 18. Evaluation of crash test no. 7069-3.
{32-in (813-mm) F-Shape Bridge Railing [1,800 lb (817 kg)|60.1 mi/h (96.7 km/h)|21.4 degrees]}

	CRITERIA	TEST RESULTS	PASS/FAIL*
A.	Must contain vehicle	Vehicle was contained	Pass
B.	Debris shall not penetrate passenger compartment	No debris penetrated passenger compartment	Pass
C.	Passenger compartment must have essentially no deformation	Acceptable deformation	Pass
D.	Vehicle must remain upright	Vehicle remained upright	Pass
E.	Must smoothly redirect the vehicle	Vehicle was smoothly redirected	Pass
F.	Effective coefficient of friction μ Assessment 0 - .25 Good .26 - .35 Fair > .35 Marginal	μ Assessment .33 Fair	Pass
G.	Shall be less than Occupant Impact Velocity - ft/s (m/s) Longitudinal Lateral 30 (9.2) 25 (7.6) Occupant Ridedown Accelerations - g's Longitudinal Lateral 15 15	Occupant Impact Velocity - ft/s (m/s) Longitudinal Lateral 19.0 (5.8) 23.7 (7.2) Occupant Ridedown Accelerations - g's Longitudinal Lateral -2.1 4.9	Pass
H.	Exit angle shall be less than 12 degrees	Exit angle was 6.2 degrees	Pass

* A, B, C, D and G are required. E, F, and H are desired. (See table 1)

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Test Number 7069-4

Vehicle:	1981 Chevrolet Pickup
Test Inertia Weight:	5,440 lb (2 470 kg)
Gross Static Weight:	5,780 lb (2 624 kg)
Impact Speed:	65.4 mi/h (105.2 km/h)
Impact Angle:	20.4 deg

The vehicle impacted the bridge railing at midlength. At approximately 0.013 s after impact the right front wheel began to ride up the face of the bridge railing, and at 0.019 s the right front tire aired out. The vehicle began to redirect as the rear end began to slide toward the bridge railing. The dummies began to move abruptly to the right at 0.046 s, and at 0.106 s the passenger dummy's head shattered the right side window glass. At 0.139 s the left front wheel left the ground and at 0.141 s the rear of the vehicle slapped the bridge railing and aired out the right rear tire. By 0.154 s the vehicle was totally airborne and remained so as it became parallel with the railing (at 0.179 s) and exited the railing (at 0.238 s). The left front wheel touched down at 0.287 s and the right touched down at 0.433 s. The vehicle exited the railing with a yaw angle of 0.4 degrees and a vehicle trajectory path of 7.4 degrees. It was in contact with the railing for 18.0 ft (5.5 m). The brakes were applied and the vehicle subsequently came to rest 240 ft (73 m) downstream and 37 ft (11 m) toward the field side of the point of impact.

The railing received only cosmetic damage (figure 52). There were tire marks on the face of the bridge railing which indicated the vehicle rose a maximum height of 24 in (610 mm) above the ground.
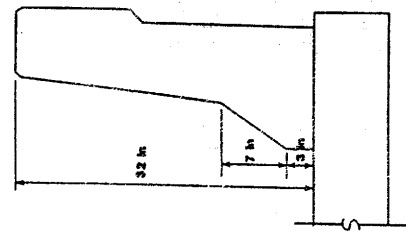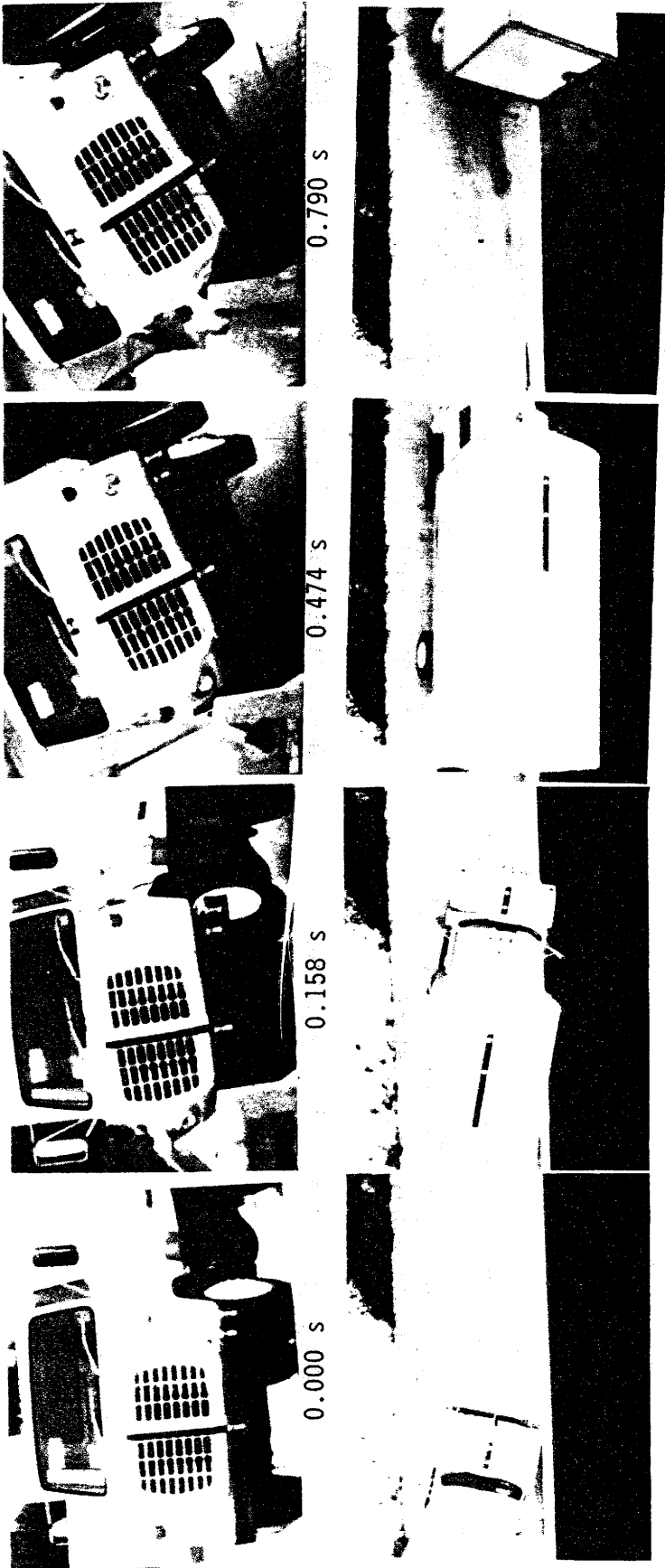
The vehicle sustained extensive damage to the right side (figure 52). Maximum crush at the right front corner at bumper height was 5.0 in (127 mm). The right front and right rear wheel rims were bent and the tires were deflated. The wheel assembly and suspension was damaged. The passenger door was bent and jammed and the window broken out. The right rear panel was dented and scraped. The hood was bent and shifted to the left. The cab of the vehicle was twisted.

The railing contained and smoothly redirected the vehicle with minimal lateral movement of the railing. There were no debris or detached elements. There was no intrusion into the occupant compartment although some deformation of the right door occurred. The vehicle trajectory at loss of contact indicated minimum intrusion into adjacent traffic lanes. The vehicle remained upright and stable during the entire test period.

Performance of the railing in this test is judged acceptable, as indicated in figure 53 and table 19.
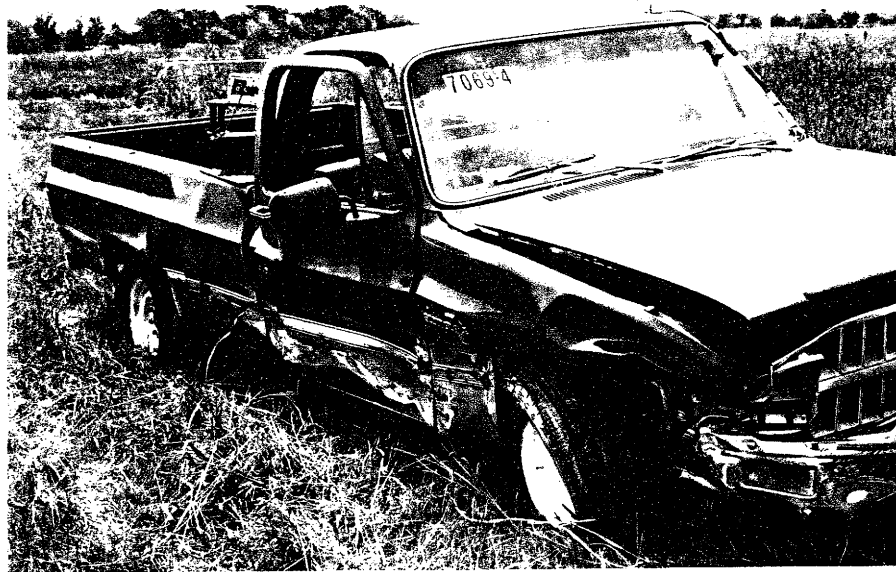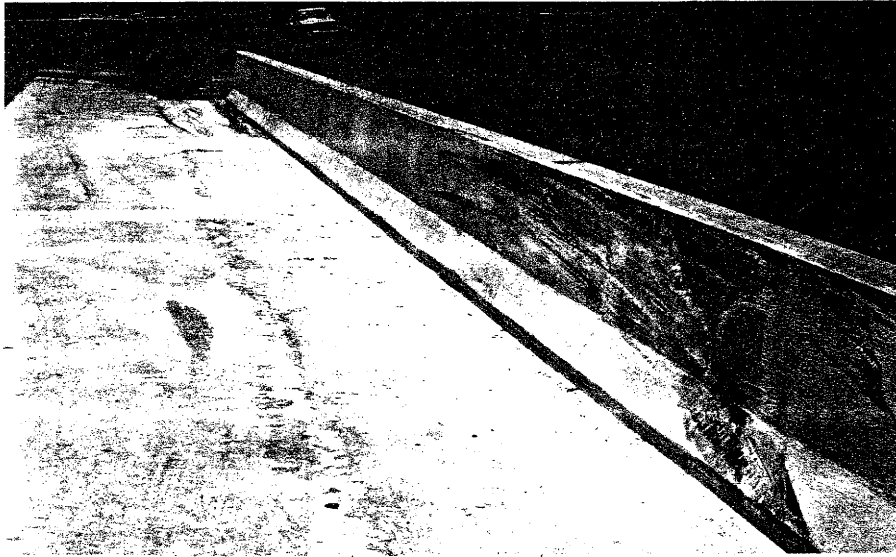
Figure 52. Vehicle and F-shape for test 7069-4.

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Test No. 7069-4
Date 7/30/87
Test Installation 32-in (813-mm)
                          F-shape Bridge Railing
Installation Length . . . 100 ft (30 m)
Vehicle . . . . 1981 Chevrolet
                          Pickup
Vehicle Weight
  Test Inertia . . . . . . 5,440 lb (2 470 kg)
  Gross Static . . . . . . 5,780 lb (2 624 kg)
Vehicle Damage Classification
  TAD 01RD4
  CDC . . . . 01FREK2 & 01RYEW3
Maximum Vehicle Crush . . 5.0 in (127 mm)

Impact Speed. . . . . . . 65.4 mi/h (105.2 km/h)
Impact Angle. . . . . . . 20.4 deg
Exit Speed. . . . . 56.9 mi/h (91.6 km/h)
Exit Trajectory . . . . . 7.4 deg
Vehicle Accelerations
  (Max. 0.050-sec Avg)
  Longitudinal. . . . . . -4.7 g
  Lateral . . . . 13.1 g
Occupant Impact Velocity
  Longitudinal. . 12.5 ft/s (3.8 m/s)
  Lateral . . . . 24.1 ft/s (7.3 m/s)
Occupant Ridedown Accelerations
  Longitudinal. . . . . . -1.2 g
  Lateral . . . . 5.9 g

Figure 53. Summary of results for test 7069-4.

32 in

7 in

3 in

1 in = 25.4 mm

Table 19. Evaluation of crash test no. 7069-4.
{32-in (813-mm) F-Shape Bridge Railing [5,440 lb (2 470 kg)|65.4 mi/h (105.2 km/h)|20.4 degrees]}

	CRITERIA	TEST RESULTS	PASS/FAIL*
A.	Must contain vehicle	Vehicle was contained	Pass
B.	Debris shall not penetrate passenger compartment	No debris penetrated passenger compartment	Pass
C.	Passenger compartment must have essentially no deformation	Minimal deformation	Pass
D.	Vehicle must remain upright	Vehicle did remained upright	Pass
E.	Must smoothly redirect the vehicle	Vehicle was smoothly redirected	Pass
F.	Effective coefficient of friction $\underline{\mu}$ $\underline{Assessment}$ 0 - .25 Good .26 - .35 Fair > .35 Marginal	$\underline{\mu}$ $\underline{Assessment}$ .31 Good	Pass
G.	Shall be less than Occupant Impact Velocity - ft/s (m/s) Longitudinal Lateral 30 (9.2) 25 (7.6) Occupant Ridedown Accelerations - g's Longitudinal Lateral 15 15	Occupant Impact Velocity - ft/s (m/s) Longitudinal Lateral 12.5 (3.8) 24.1 (7.3) Occupant Ridedown Accelerations - g's Longitudinal Lateral -1.2 5.9	Pass
H.	Exit angle shall be less than 12 degrees	Exit angle was 7.3 degrees	Pass

* A, B, C, and D are required. E, F, G, and H are desired. (See table 1)

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Vehicle: 1982 Ford Single-Unit Truck
Test Inertia Weight: 18,050 lb (8 195 kg)
Empty Weight: 13,050 lb (6 288 kg)
Impact Speed: 46.7 mi/h (75.1 km/h)
Impact Angle: 15.0 deg

[NOTE: In test 7069-8, the engine of the test vehicle (which was remotely controlled) stalled, causing the impact speed of the test vehicle to be lower than specified in the crash test requirements (46.7 mi/h vs 50 mi/h). The test was repeated (7069-9) and again the impact speed was too low (47.3 mi/h vs 50 mi/h). In a third test (7069-11), an acceptable impact speed of 52.1 mi/h was attained.]

The vehicle impacted the bridge railing at midlength. At approximately 0.021 s after impact the right front wheel began to ride up the face of the bridge railing, and at 0.163 s the left front tire began to leave the ground. The vehicle began to redirect at 0.184 s as the rear end began to slide toward the bridge railing. At 0.343 s the left rear wheels left the ground, and at approximately 0.448 s the rear of the vehicle slapped the bridge railing. By approximately 0.495 s the vehicle became parallel with the railing and was continuing to roll to the right. As the vehicle continued along the railing, the lower edge of the bed rode along the top of the railing. A maximum roll angle of 34 degrees was achieved at about 1.286 s. The vehicle slid off the end of the bridge railing at about 1.713 s after impact. Total length of contact with the railing was 60 ft (18 m). The brakes were applied and the vehicle subsequently came to rest 186 ft (57 m) downstream.

The railing received only cosmetic damage (figure 54). There were tire marks on the face of the bridge railing and along the top. The top of the bridge railing was scraped along the remaining length from the lower edge of the bed of the truck.

The vehicle sustained extensive damage to the right side (figure 54). Maximum crush at the right front corner at bumper height was 6.0 in (152 mm). The right front wheel rim was bent and the tire damaged. The spring and spring shackle was broken loose from the axle. The steering gear box and steering cylinder was damaged. Also, the fuel tank broke loose from the truck.

The railing contained and smoothly redirected the vehicle with no lateral movement of the railing. There were no debris or detached elements. There was no intrusion into the occupant compartment. The vehicle trajectory at loss of contact indicated minimum intrusion into adjacent traffic lanes. The vehicle remained upright and marginally stable during the entire test period.
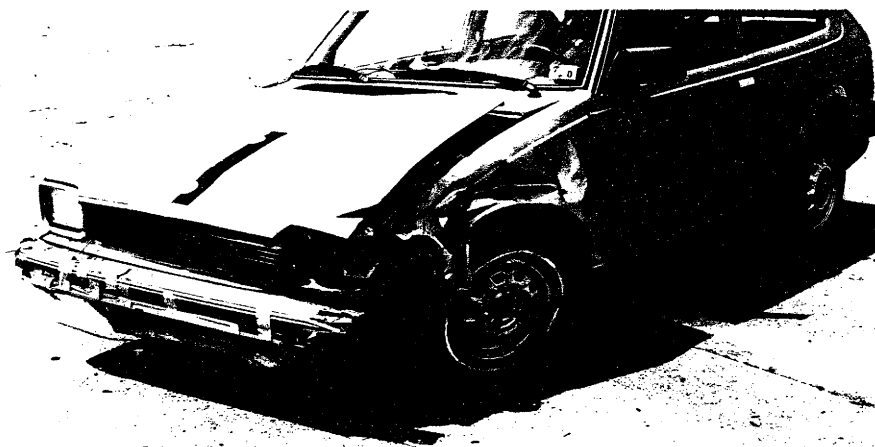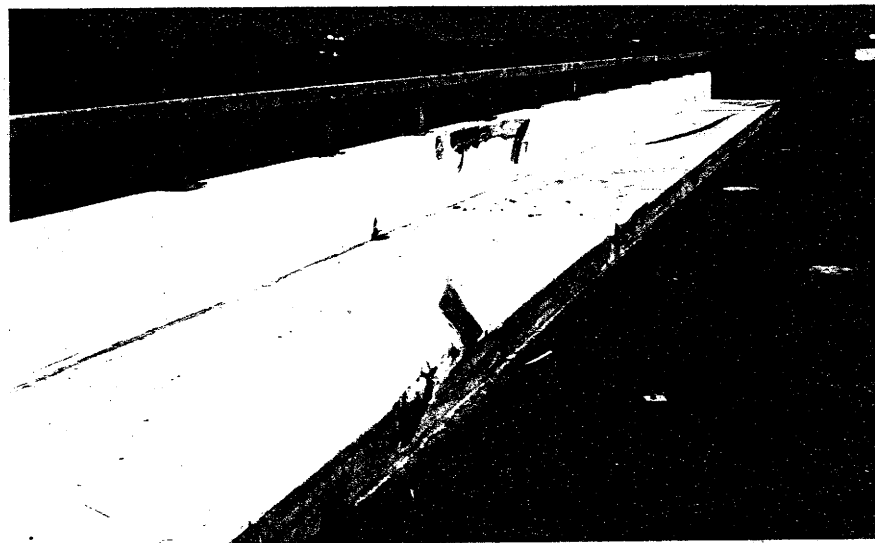
Performance of the railing in this test is judged acceptable, as indicated in figure 55 and table 20.
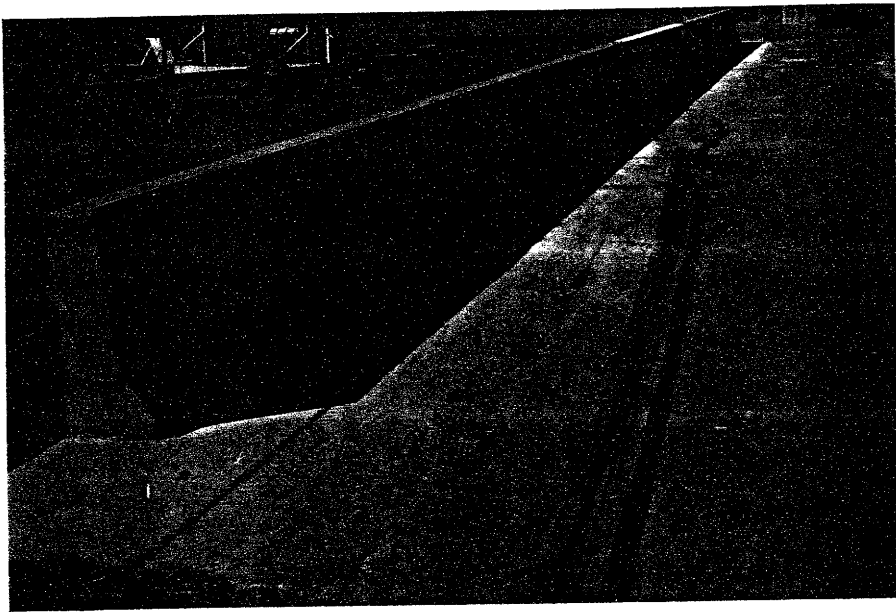
Figure 54. Vehicle and F-shape for test 7069-8.

110
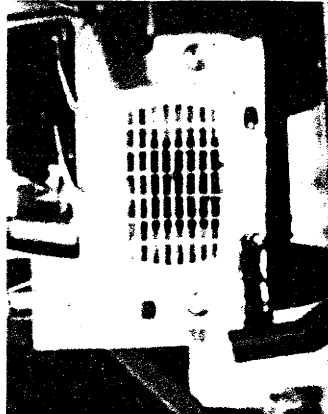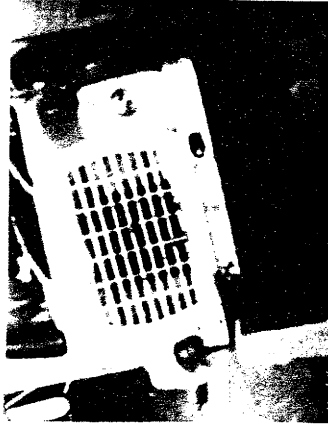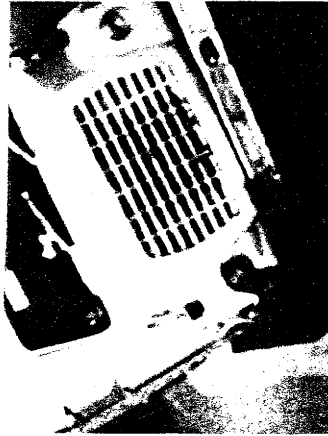
| | 0.000 s | 0.364 s | 0.727 s | 1.091 s |

Test No. . . . . : 7069-8
Date . . . . : 1/28/88
Test Installation . . . : 32-in (813-mm)
                          F-shape Bridge Railing
Installation Length . . : 100 ft (30 m)
Vehicle . . . . : 1982 Ford
                          Single-Unit Truck
Vehicle Weight
  Empty Weight . . . . . : 13,050 lb (6 288 kg)
  Test Inertia . . . . . : 18,050 lb (8 195 kg)
Maximum Vehicle Crush . : 6.0 in (152 mm)

Impact Speed. . . . . : 46.7 mi/h (75.1 km/h)
Impact Angle. . . . . : 15.0 deg
Exit Speed . . . . . : N/A
Exit Trajectory . . . : 5.0 deg
Vehicle Accelerations
  (Max. 0.050-sec Avg)
  Longitudinal. . . . : -2.2 g
  Lateral . . . . . : 3.4 g
Occupant Impact Velocity
  Longitudinal. . . . : 11.8 ft/s (3.6 m/s)
  Lateral . . . . . : 9.2 ft/s (2.8 m/s)
Occupant Ridedown Accelerations
  Longitudinal. . . . : -3.8 g
  Lateral . . . . . : 6.1 g

1 in = 25.4 mm

Figure 55. Summary of results for test 7069-8.

111

Table 20. Evaluation of crash test no. 7069-8.
{32-in (813-mm) F-shape Bridge Rail [18,050 lb (8 195 kg)|46.7 mi/h (75.1 km/h)|15.0 degrees]}

	CRITERIA	TEST RESULTS	PASS/FAIL*
A.	Must contain vehicle	Vehicle was contained	Pass
B.	Debris shall not penetrate passenger compartment	No debris penetrated passenger compartment	Pass
C.	Passenger compartment must have essentially no deformation	Acceptable deformation	Pass
D.	Vehicle must remain upright	Vehicle remained upright	Pass
E.	Must smoothly redirect the vehicle	Vehicle was smoothly redirected	Pass
F.	Effective coefficient of friction μ Assessment 0 - .25 Good .26 - .35 Fair > .35 Marginal	μ Assessment .76 Not applicable because not redirected into traffic.	Pass
G.	Shall be less than Occupant Impact Velocity - ft/s (m/s) Longitudinal Lateral 30 (9.2) 25 (7.6) Occupant Ridedown Accelerations - g's Longitudinal Lateral 15 15	Occupant Impact Velocity - ft/s (m/s) Longitudinal Lateral 11.8 (3.6) 9.2 (2.8) Occupant Ridedown Accelerations - g's Longitudinal Lateral -3.8 6.1	N/A
H.	Exit angle shall be less than 12 degrees	about 5 degrees	N/A

* A, B, C, and D are required. E, F, and H are desired. G is not applicable for this test. (See table 1)

112

<u>Test Number 7069-9</u>

Vehicle:	1982 Ford Single-Unit Truck
Test Inertia Weight:	18,050 lb (8 195 kg)
Empty Weight:	13,050 lb (6 288 kg)
Impact Speed:	47.3 mi/h (76.1 km/h)
Impact Angle:	15.3 deg

The vehicle impacted the bridge railing at midlength. At approximately 0.017 s after impact the right front wheel began to ride up the face of the bridge railing, and at 0.153 s the left front tire began to leave the ground. The vehicle began to redirect at 0.156 s as the rear end began to slide toward the bridge railing. At 0.292 s the left rear wheels left the ground, and at 0.421 s the rear of the vehicle contacted the bridge railing. By approximately 0.523 s the vehicle became parallel with the railing and was continuing to roll to the right. As the vehicle continued along the railing, the lower edge of the bed rode along the top of the railing. A maximum roll angle of 25 degrees was achieved at about 0.886 s. The vehicle slid off the end of the bridge railing at about 1.326 s after impact. The brakes were applied and the vehicle subsequently came to rest 150 ft (46 m) downstream.

The railing received only cosmetic damage (figure 56). There were tire marks on the face of the railing and along the top. The top of the bridge railing was scraped along the remaining length from the lower edge of the bed of the truck.

The vehicle sustained extensive damage to the right side (figure 56). Maximum crush at the right front corner at bumper height was 16.0 in (406 mm). The right front wheel rim was bent and the tire damaged. The spring and spring shackle was broken loose from the axle and the axle torn loose on the left side. The steering gear box and steering cylinder was damaged. Also, the fuel tank broke loose from the truck.

The railing contained and smoothly redirected the vehicle with no lateral movement of the railing. There was no debris or detached elements. There was no intrusion into the occupant compartment. The vehicle trajectory at loss of contact indicated minimum intrusion into adjacent traffic lanes. The vehicle remained upright and marginally stable during the entire test period.

Performance of the railing in this test is judged acceptable, as indicated in figure 57 and table 21.
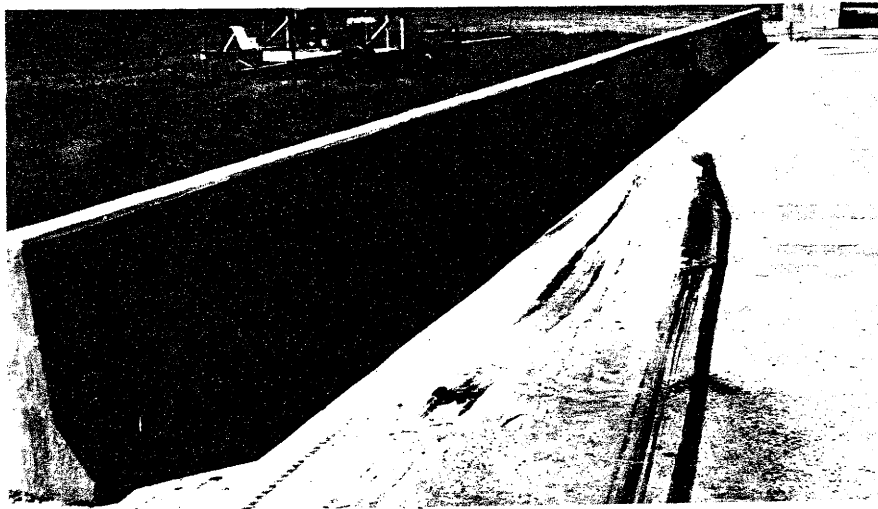
Figure 56. Vehicle and F-shape for test 7069-9.

Impact Speed. . . .	47.3 mi/h (76.1 km/h)
Impact Angle. . . .	15.3 deg
Exit Speed. . . .	34.5 mi/h (55.5 km/h)
Exit Trajectory . .	2.0 deg
Vehicle Accelerations	
(Max. 0.050-sec Avg)	
Longitudinal. .	-2.0 g
Lateral	2.9 g
Occupant Impact Velocity	
Longitudinal. .	11.7 ft/s (3.6 m/s)
Lateral	9.9 ft/s (3.0 m/s)
Occupant Ridedown Accelerations	
Longitudinal. .	-2.7 g
Lateral	6.8 g

Test No.	7069-9
Date	2/23/88
Test Installation . . .	32-in (813-mm) F-shape Bridge Railing
Installation Length. . .	100 ft (30 m)
Vehicle	1982 Ford Single-Unit Truck
Vehicle Weight	
Empty Weight	13,050 lb (6 288 kg)
Test Inertia	18,050 lb (8 195 kg)
Maximum Vehicle Crush .	16.0 in (406 mm)

1 in = 25.4 mm

Figure 57. Summary of results for test 7069-9.

115

Table 21. Evaluation of crash test no. 7069-9.
{32 in (813-mm) F-shape Bridge Railing [18,050 lb (8 195 kg)|47.3 mi/h (76.1 km/h)|15.3 degrees]}

	CRITERIA	TEST RESULTS	PASS/FAIL
A.	Must contain vehicle	Vehicle was contained	Pass
B.	Debris shall not penetrate passenger compartment	No debris penetrated passenger compartment	Pass
C.	Passenger compartment must have essentially no deformation.	Acceptable deformation	Pass
D.	Vehicle must remain upright	Vehicle remained upright	Pass
E.	Must smoothly redirect the vehicle	Vehicle was smoothly redirected	Pass
F.	Effective coefficient of friction μ Assessment 0 - .25 Good .26 - .35 Fair > .35 Marginal	μ Assessment .09 Good	Pass
G.	Shall be less than Occupant Impact Velocity - ft/s (m/s) Longitudinal Lateral 30 (9.2) 25 (7.6) Occupant Ridedown Accelerations - g's Longitudinal Lateral 15 15	Occupant Impact Velocity - ft/s (m/s) Longitudinal Lateral 11.7 (3.6) 9.9 (3.0) Occupant Ridedown Accelerations - g's Longitudinal Lateral -2.7 6.8	N/A N/A
H.	Exit angle shall be less than 12 degrees	about 2 degrees	

* A, B, C, D are required. E, F, and H are desired. G is not applicable for this test. (See table 1)

116

Test Number 7069-11

Vehicle:	1982 Ford Single-Unit Truck
Test Inertia Weight:	18,000 lb (8 172 kg)
Empty Weight:	13,530 lb (6 145 kg)
Impact Speed:	52.1 mi/h (83.8 km/h)
Impact Angle:	14.8 deg

The vehicle impacted the bridge railing at midlength. At approximately 0.022 s after impact the right front wheel began to ride up the face of the bridge railing, and at 0.132 s the left front tire began to leave the ground. The vehicle began to redirect at 0.144 s as the rear end began to slide toward the bridge railing. At 0.240 s the left rear wheels left the ground, and at 0.350 s the rear of the vehicle slapped the bridge railing. By approximately 0.524 s the vehicle became parallel with the railing and was continuing to roll to the right. As the vehicle continued along the railing, the lower edge of the bed rode along the top of the railing. A maximum roll angle of 31 degrees was achieved at about 0.683 s. The vehicle slid off the end of the bridge railing at approximately 1.346 s after impact. The brakes were applied and the vehicle subsequently came to rest 231 ft (70 m) downstream.

The railing received only cosmetic damage (figure 58). There were tire marks on the face of the bridge railing and along the top. The top of the bridge railing was scraped along the remaining length from the lower edge of the bed of the truck. The vehicle was in contact with the bridge railing for 39 ft (12 m).

The vehicle sustained extensive damage to the right side as shown in figure 58. Maximum crush at the right front corner at bumper height was 20.0 (508 mm). The front axle was torn loose which caused damage to the springs, shackles, U-bolts, and tie rods. The steering arm and cylinder were damaged and the oil pan was dented. Also, the fuel tank broke loose from the truck.

The railing contained and smoothly redirected the vehicle with no lateral movement of the railing. There was no debris or detached elements. There was no intrusion into the occupant compartment. The vehicle trajectory at loss of contact indicated minimum intrusion into adjacent traffic lanes. The vehicle remained upright and marginally stable during the entire test period.

Performance of the railing in this test is judged acceptable, as indicated in figure 59 and table 22.

Figure 58. Vehicle and F-shape for test 7069-11.

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0.000 s	0.158 s	0.474 s	0.790 s

Test No. . . . . : 7069-11
Date . . . . : 3/30/88
Test Installation . . . : 32-in (813-mm)
       F-shape Bridge Railing
Installation Length . . : 100 ft (30 m)
Vehicle . . . . : 1982 Ford 7000
       Single-Unit Truck
Vehicle Weight
  Empty Weight . . . . . : 13,530 lb (6 145 kg)
  Test Inertia . . . . . : 18,000 lb (8 172 kg)
Maximum Vehicle Crush . : 20.0 in (508 mm)

Impact Speed. . . . . . : 52.1 mi/h (83.8 km/h)
Impact Angle. . . . . . : 14.8 deg
Exit Speed . . . . . . : Not Available
Exit Trajectory . . . . : 0 deg
Vehicle Accelerations
  (Max. 0.050-sec Avg)
  Longitudinal. . . . . : -1.4 g
  Lateral . . . . : 3.9 g
Occupant Impact Velocity
  Longitudinal. . . . . : 5.7 ft/s (1.7 m/s)
  Lateral . . . . : 8.2 ft/s (2.5 m/s)
Occupant Ridedown Accelerations
  Longitudinal. . . . . : 1.3 g
  Lateral . . . . : 5.4 g

1 in = 25.4 mm

Figure 59. Summary of results for test 7069-11.

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Table 22. Evaluation of crash test no. 7069-11.
{32-in (813-mm) F-Shape Bridge Railing [18,000 lb (8 172 kg)|52.1 mi/h (83.8 km/h)|14.8 degrees]}

	CRITERIA	TEST RESULTS	PASS/FAIL*
A.	Must contain vehicle	Vehicle was contained	Pass
B.	Debris shall not penetrate passenger compartment	No debris penetrated passenger compartment	Pass
C.	Passenger compartment must have essentially no deformation	Acceptable information	Pass
D.	Vehicle must remain upright	Vehicle remained upright	Pass
E.	Must smoothly redirect the vehicle	Vehicle was smoothly redirected	Pass
F.	Effective coefficient of friction μ Assessment 0 - .25 Good .26 - .35 Fair > .35 Marginal	μ Assessment .12 Good	Pass
G.	Shall be less than Occupant Impact Velocity - ft/s (m/s) Longitudinal Lateral 30 (9.2) 25 (7.6) Occupant Ridedown Accelerations - g's Longitudinal Lateral 15 15	Occupant Impact Velocity - ft/s (m/s) Longitudinal Lateral 5.7 (1.7) 8.2 (2.5) Occupant Ridedown Accelerations - g's Longitudinal Lateral 1.3 5.4	N/A N/A
H.	Exit angle shall be less than 12 degrees	about 0 degrees	Pass

* A, B, C, and D are required. E, F, and H are desired. G is not applicable for this test. (See table 1)

120

BR27C on Sidewalk

<u>Test Number 7069-24</u>

Vehicle:	1982 Honda Civic
Test Inertia Weight:	1,800 lb (817 kg)
Gross Static Weight:	1,965 lb (892 kg)
Impact Speed:	61.7 mi/h (99.3 km/h)
Impact Angle:	18.7 deg

At approximately 0.025 s after impact, the left front corner of the vehicle began to deform and at 0.185 s the right front tire impacted the curb. The vehicle impacted the concrete parapet at 0.219 s traveling at a speed of 55.5 mi/h (89.3 km/h) and an angle of 18.1 degrees. At 0.267 s the vehicle began to redirect significantly, and at 0.302 s the right rear tire impacted the curb. The vehicle briefly lost contact with the parapet at 0.397 s, became totally airborne, and remained as such as it began to travel parallel with the bridge railing at a speed of 50.9 mi/h (81.9 km/h). The rear of the vehicle contacted the parapet at 0.440 s and then exited the bridge railing at 0.521 s traveling at a speed of 50.3 (80.9 km/h) and an exit angle of 1.0 degrees. The vehicle was in contact with the bridge railing system for 12.25 ft (3.7 m). As the vehicle exited the bridge railing installation, the brakes were applied. The vehicle yawed clockwise and subsequently came to rest 187 ft (57 m) down and 50 ft (15 m) toward the traffic side of the point of impact.

The bridge railing system received minimal damage (figure 60). There was no measurable permanent deformation to the metal railing elements; however, the left corner of the bumper had snagged post 6 (leaving plastic trim). Also, posts 5 and 6 were pulled up such that the washers rotated freely under the nuts on the front side of the railing. There was only cosmetic damage to the concrete parapet, i.e., tire marks on the concrete parapet from post 5 on past post 6 and then again between posts 8 and 9 where the vehicle contacted the parapet the second time.

The vehicle sustained damage to the left side (figure 60). Maximum crush at the left front corner at bumper height was 7.5 in (191 mm). The left front strut was bent and the left front wheel was pushed back reducing the wheelbase on the driver side by 3 in (76 mm). Also damage was done to the front bumper, hood, left front quarter panel, left rear quarter panel, rear bumper, left front and rear tires and rims, and right front tire.

The railing contained the vehicle with no lateral movement of the railing. There was no intrusion of railing components into the occupant compartment and no debris to present undue hazard to other traffic. The integrity of the occupant compartment was maintained with no intrusion and no deformation. The vehicle remained upright and relatively stable during the collision. The bridge railing system smoothly redirected the vehicle. Although the lateral ridedown acceleration of 17.2 g's was slightly above the recommended limit, performance was judged acceptable for this category because it was well within the limits of the other three occupant risk factors. The vehicle trajectory at loss of contact indicated minimum intrusion into adjacent traffic lanes.

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Figure 60. Vehicle and railing for test 7069-24.

Performance of the railing in this test is judged acceptable, as indicated in figure 61 and table 23.

0.000 s	0.216 s	0.351 s	0.521 s
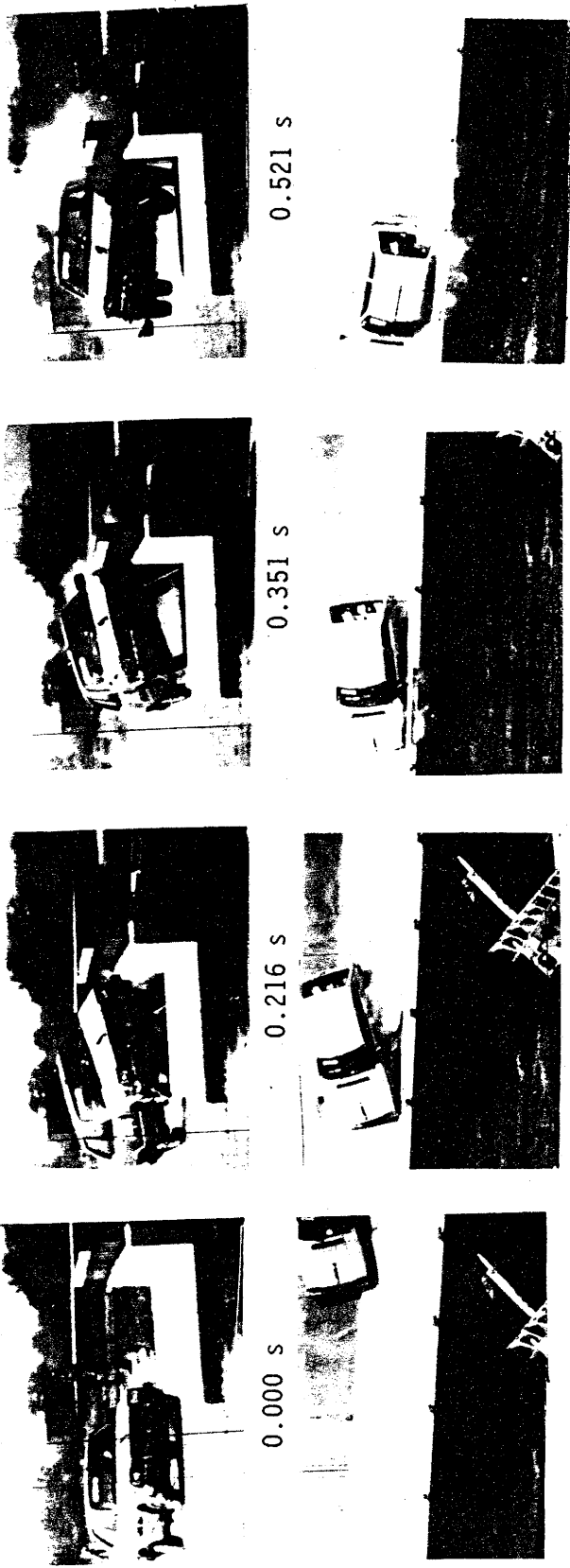
Test No. 7069-24
Date 03/31/92
Test Installation . . . . BR27C Bridge Railing
                            on sidewalk
Installation Length . . . 100 ft (30 m)

Test Vehicle . . . . 1982 Honda Civic
Vehicle Weight
  Test Inertia . . . . . . 1,800 lb (817 kg)
  Gross Static . . . . . . 1,965 lb (892 kg)
Vehicle Damage Classification
  TAD 11LFQ3
  CDC . . . . 11FLEK2 & 11LFES2
Maximum Vehicle Crush . . 7.5 in (191 mm)

Impact Speed. . . . . . . 61.7 mi/h (99.3 km/h)
Impact Angle. . . . . . . 18.7 deg
Speed at Parallel . . . . 50.9 mi/h (81.9 km/h)
Exit Speed . . . . 50.3 mi/h (80.9 km/h)
Exit Trajectory . . . . . 1.0 deg
Vehicle Accelerations
  (Max. 0.050-sec Avg) at true c.g.
  Longitudinal. . . . . . -5.6 g
  Lateral . . . . -9.3 g
Occupant Impact Velocity at true c.g.
  Longitudinal. . . . . . 15.3 ft/s (4.7 m/s)
  Lateral . . . . 6.5 ft/s (2.0 m/s)
Occupant Ridedown Accelerations
  Longitudinal. . . . . . -3.8 g
  Lateral . . . . -17.2 g
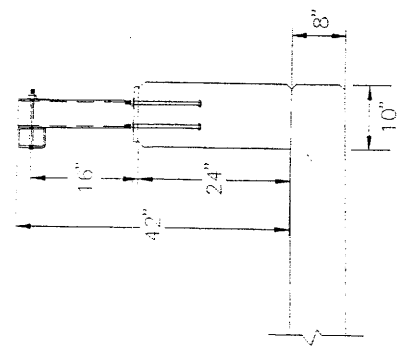
Figure 61. Summary of results for test 7069-24.

1 in = 25.4 mm

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Table 23. Evaluation of crash test no. 7069-24.
{BR27C bridge railing on sidewalk [1,800 lb (817 kg)|61.7 mi/h (99.3 km/h)|18.7 degrees]}

	CRITERIA	TEST RESULTS	PASS/FAIL*
A.	Must contain vehicle	Vehicle was contained	Pass
B.	Debris shall not penetrate passenger compartment	No debris penetrated passenger compartment	Pass
C.	Passenger compartment must have essentially no deformation	No deformation	Pass
D.	Vehicle must remain upright	Vehicle did remain upright	Pass
E.	Must smoothly redirect the vehicle	Vehicle was smoothly redirected	Pass
F.	Effective coefficient of friction μ — Assessment 0 - .25 — Good .26 - .35 — Fair > .35 — Marginal	μ — Assessment .38 (Impact @ curb) — Marginal .11 (Impact @ rail) — Good	Pass
G.	Shall be less than Occupant Impact Velocity - ft/s (m/s) Longitudinal — Lateral 30 (9.2) — 25 (7.6) Occupant Ridedown Accelerations - g's Longitudinal — Lateral 15 — 15	Occupant Impact Velocity - ft/s (m/s) Longitudinal — Lateral 15.3 (4.7) — 6.5 (2.0) Occupant Ridedown Accelerations - g's Longitudinal — Lateral -3.8 — -17.2	Pass Pass
H.	Exit angle shall be less than 12 degrees	Exit angle was 1.0 degrees	Pass

* A, B, C, D and G are required. E, F, and H are desired. (See table 1)

125

Vehicle:	1984 GMC Pickup
Test Inertia Weight:	5,400 lb (2 452 kg)
Gross Static Weight:	5,568 lb (2 528 kg)
Impact Speed:	62.6 mi/h (100.7 km/h)
Impact Angle:	19.4 deg

The vehicle impacted the curb approximately 8.8 ft (2.7 m) downstream from the end. As the left front wheel of the vehicle mounted the curb, the tire was deflated. At approximately 0.064 s after impact, the vehicle began to redirect, and at 0.118 s the left rear tire contacted the curb. The vehicle bumper impacted the concrete parapet (near post 4) at 0.150 s traveling at a speed of 59.8 mi/h (96.2 km/h) and an angle of 17.9 degrees. At 0.167 s the right front wheel contacted the curb and the vehicle impacted the metal railing element. By 0.214 s the vehicle began to redirect significantly, and by 0.329 s the vehicle was traveling parallel with the bridge railing at a speed of 56.7 mi/h (91.2 km/h). The rear of the vehicle contacted the concrete parapet at 0.348 s and then exited the bridge railing at 0.463 s traveling at a speed of 53.5 (86.1 km/h) and an exit angle of 5.4 degrees. The vehicle was in contact with the bridge railing system for a total of 13.0 ft (4.0 m). As the vehicle exited the bridge railing installation, the brakes were applied. The vehicle yawed counter-clockwise and subsequently came to rest 210 ft (64 m) down and 6 ft (2 m) toward the field side of the point of impact.

The railing system received minimal damage (figure 62). There was no measurable permanent deformation to the metal railing elements; however, the left corner of the bumper had snagged post 5 and pulled it up such that the washer rotated freely under the nut on the left front side of the railing. There was only cosmetic damage to the concrete parapet, i.e., tire marks on the concrete parapet from post 4 to post 6.

The vehicle sustained damage to the left side (figure 62). Maximum crush at the left front corner at bumper height was 12.0 in (305 mm) and the right front corner was deformed outward 7.0 in (178 mm). The left front wheel was pushed back reducing the wheelbase on the driver side by 2.25 in (57 mm). Also, damage was done to the front bumper, hood, grill, the left front quarter panel, left door and glass, left rear quarter panel, rear bumper and tailgate, left front tire and rim, and right front tire. The welds on the left rear rim broke and the tire separated from the rim.

The railing contained the vehicle with no lateral movement of the railing. There was no intrusion of railing components into the occupant compartment and no debris to present undue hazard to other traffic. The integrity of the occupant compartment was maintained with no intrusion and no deformation. The vehicle remained upright and relatively stable during the collision. The bridge railing system smoothly redirected the vehicle. The effective coefficient of friction was considered good. The occupant risk factors were well within the specified limits. The vehicle trajectory at loss of contact indicates minimum intrusion into adjacent traffic lanes.

126
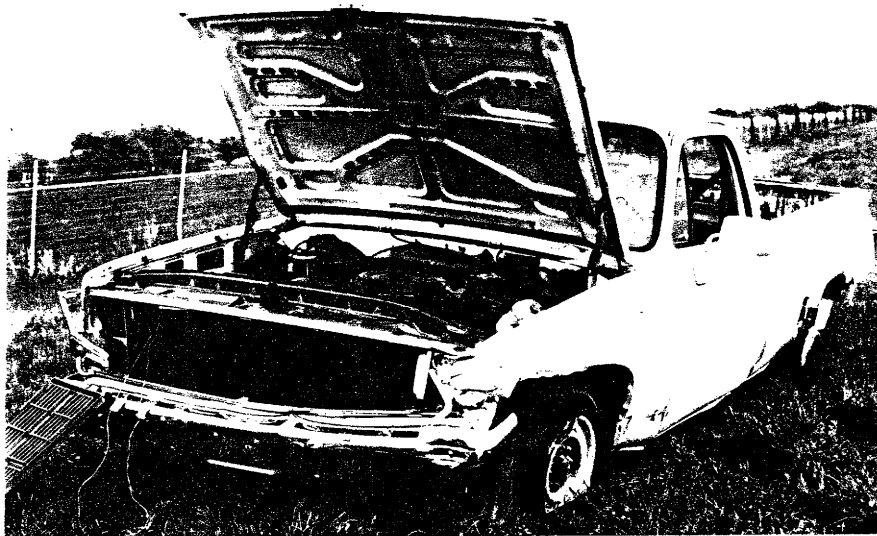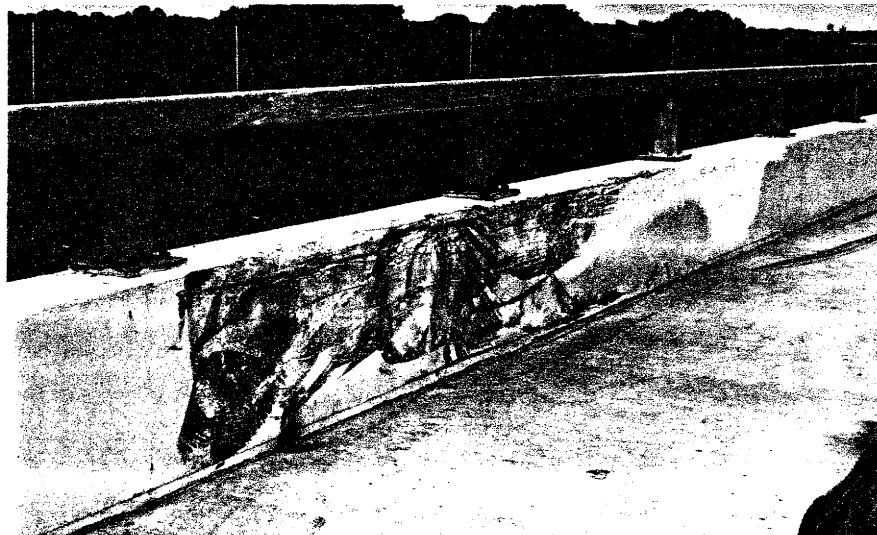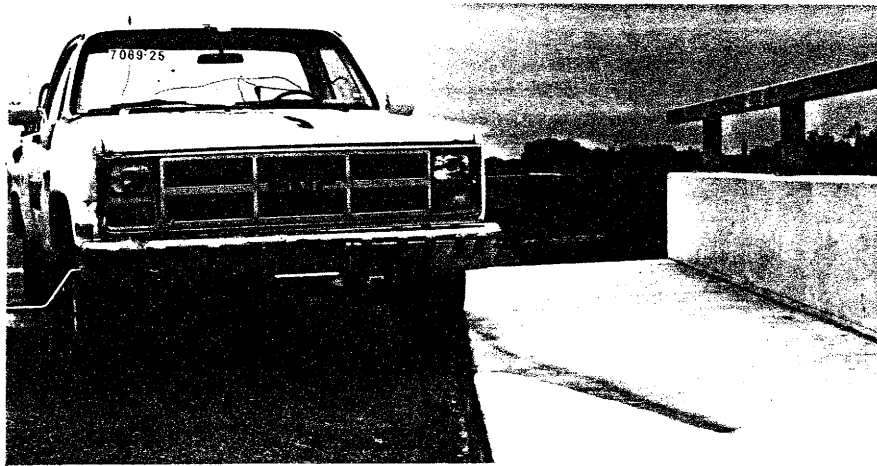
Figure 62. Vehicle and railing for test 7069-25.

Performance of the railing in this test is judged acceptable, as indicated in figure 63 and table 24.

129
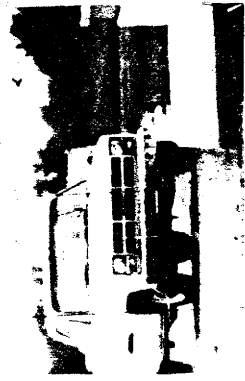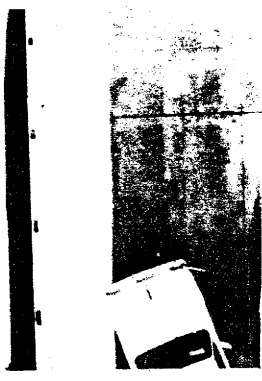
0.000 s	0.191 s

0.319 s	0.463 s
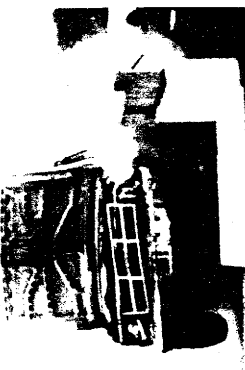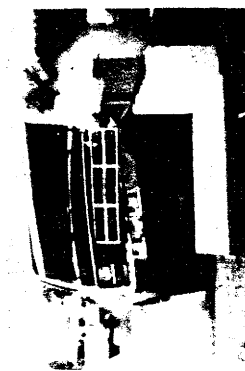
Test No. 7069-25
Date 04/02/92
Test Installation . . . . BR27C Bridge Railing
                              on sidewalk
Installation Length . . . 100 ft (30 m)

Test Vehicle . . . . 1984 GMC Sierra
Vehicle Weight   Pickup
  Test Inertia . . . . 5,400 lb (2 452 kg)
  Gross Static . . . . 5,568 lb (2 528 kg)
Vehicle Damage Classification
  TAD . . . . 11LFQ4 & 11LD4
  CDC . . . . 11FLEK2 & 11LDEW2
Maximum Vehicle Crush . . 12.0 in (305 mm)

Impact Speed. . . . . . 62.6 mi/h (100.7 km/h)
Impact Angle. . . . . . 19.4 deg
Speed at Parallel . . . 56.7 mi/h (91.2 km/h)
Exit Speed . . . . 53.5 mi/h (86.1 km/h)
Exit Trajectory . . . . 5.4 deg
Vehicle Accelerations
  (Max. 0.050-sec Avg) at true c.g.
  Longitudinal. . . . . -4.6 g
  Lateral . . . . -9.3 g
Occupant Impact Velocity at true c.g.
  Longitudinal. . . . . 12.9 ft/s (3.9 m/s)
  Lateral . . . . 19.9 ft/s (6.1 m/s)
Occupant Ridedown Accelerations
  Longitudinal. . . . . -4.4 g
  Lateral . . . . -10.8 g
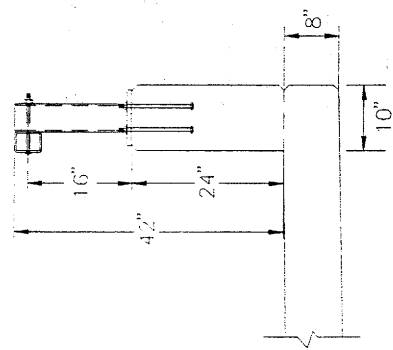
Figure 63. Summary of results for test 7069-25.

42"
16"
24"
8"
10"

1 in = 25.4 mm

Table 24. Evaluation of crash test no. 7069-25.
{BR27C bridge railing on sidewalk [5,400 lb (2 452 kg)|62.6 mi/h (100.7 km/h)|19.4 degrees]}

	CRITERIA	TEST RESULTS	PASS/FAIL*
A.	Must contain vehicle	Vehicle was contained	Pass
B.	Debris shall not penetrate passenger compartment	No debris penetrated passenger compartment	Pass
C.	Passenger compartment must have essentially no deformation	No deformation	Pass
D.	Vehicle must remain upright	Vehicle did remain upright	Pass
E.	Must smoothly redirect the vehicle	Vehicle was smoothly redirected	Pass
F.	Effective coefficient of friction μ — Assessment 0 - .25 — Good .26 - .35 — Fair > .35 — Marginal	μ — Assessment .11 (Impact @ curb) — Good .01 (Impact @ rail) — Good	Pass
G.	Shall be less than Occupant Impact Velocity - ft/s (m/s) Longitudinal — Lateral 30 (9.2) — 25 (7.6) Occupant Ridedown Accelerations - g's Longitudinal — Lateral 15 — 15	Occupant Impact Velocity - ft/s (m/s) Longitudinal — Lateral 12.9 (3.9) — 19.9 (6.1) Occupant Ridedown Accelerations - g's Longitudinal — Lateral -4.4 — -10.8	Pass
H.	Exit angle shall be less than 12 degrees	Exit angle was 5.4 degrees	Pass

* A, B, C, and D are required. E, F, G, and H are desired. (See table 1)

130

Vehicle: 1980 Ford Single-Unit Truck
Test Inertia Weight: 18,000 lb (8 172 kg)
Empty Weight: 10,550 lb (4 790 kg)
Impact Speed: 51.0 mi/h (82.0 km/h)
Impact Angle: 13.7 deg

At approximately 0.084 s after impact, the vehicle began a slight counter-clockwise yaw, and at 0.220 s the left rear tire contacted the curb of the sidewalk. The vehicle bumper impacted the concrete parapet (3 ft (1 m) downstream of post 7) at 0.290 s traveling at a speed of 47.9 mi/h (77.1 km/h) and an angle of 14.4 degrees. At 0.307 s the left front wheel contacted the parapet, and at 0.368 s the right front wheel and part of the hub broke loose from the axle. By 0.431 s the vehicle began to redirect and at 0.502 s the axle contacted the curb. The vehicle was moving parallel with the bridge railing by 0.590 s traveling at a speed of 44.8 mi/h (72.1 km/h). The rear of the vehicle contacted the concrete parapet at 0.607 s and, as the vehicle continued forward, the lower edge of the vehicle's cargo box pulled the metal railing off posts 10 through 14. The front of the cab dropped off the end of the curb at 1.325 s and, as the vehicle exited the test site, it rode over the dislodged axle and drive shaft. The vehicle was in contact with the bridge railing system for a total of 63 ft (19 m). The vehicle subsequently came to rest 195 ft (59 m) from the point of impact.

The railing system received moderate damage (figure 64). There was no measurable permanent deformation to the metal railing elements in the immediate impact area; however the bolts connecting the railing to the posts from 10 through 14 were sheared as a result of vertical load from the cargo box. There was only cosmetic damage to the concrete parapet, i.e., tire marks on the concrete parapet from post midway of posts 7 and 8 to post 11 and then again from posts 13 to 14.

The vehicle sustained damage to the left side (figure 64). Maximum crush at the left front corner at bumper height was 6.0 in (152 mm). The front axle broke loose and became separated from the vehicle as did the drive shaft. There was damage to the springs and shocks, steering box, front bumper, left front quarter panel, left door, and left front tire and rim. The lower edge of the left side of the cargo box was also damaged.

The railing contained the vehicle with minimal lateral movement of the railing. There was no intrusion of railing components into the occupant compartment and no debris to present undue hazard to other traffic. The integrity of the occupant compartment was maintained with no intrusion and no deformation. The vehicle remained upright and relatively stable during the collision. The bridge railing system smoothly redirected the vehicle. The effective coefficient of friction was considered marginal to good. The vehicle trajectory at loss of contact indicated minimum intrusion into adjacent traffic lanes.

Performance of the railing in this test is judged acceptable, as indicated in figure 65 and table 25.
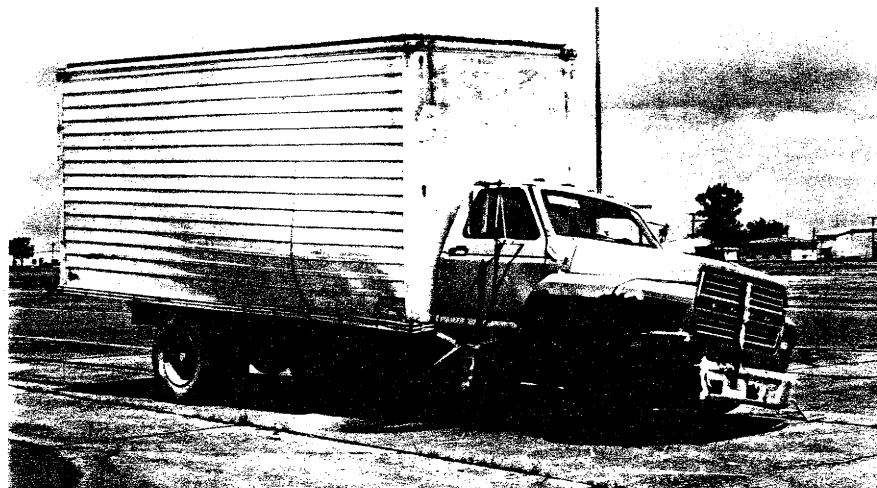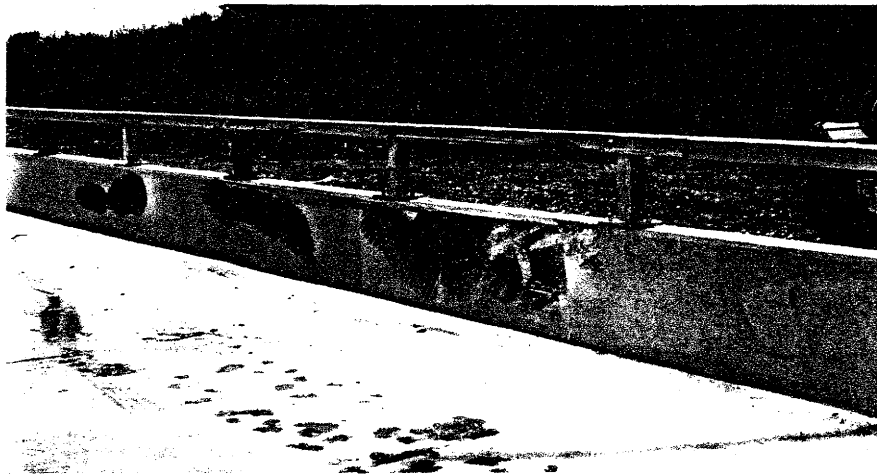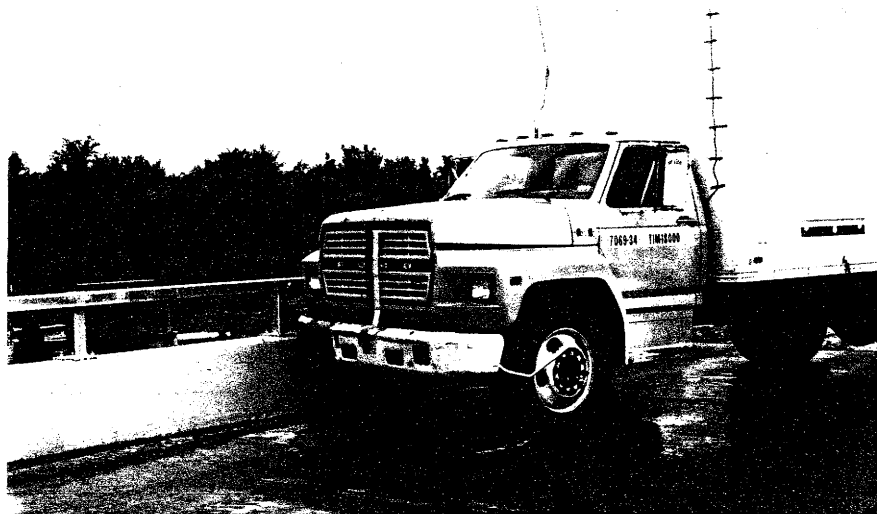
131
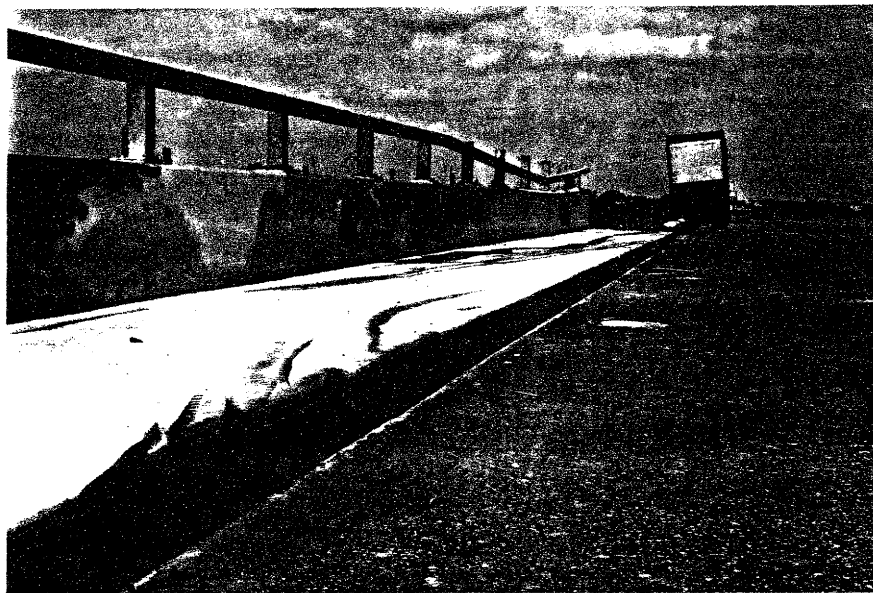
Figure 64. Vehicle and railing for test 7069-26.

Test No	.	7069-26
Date	.	04/08/92
Test Installation . .	.	BR27C Bridge Railing on sidewalk
Installation Length .	.	100 ft (30 m)
Test Vehicle	.	1980 Ford Single-Unit Truck
Vehicle Weight		
Empty Weight . .	.	10,550 lb (4 790 kg)
Test Inertia . .	.	18,000 lb (8 172 kg)
Maximum Vehicle Crush	.	12.0 in (305 mm)

Impact Speed. . . . 51.0 mi/h (82.0 km/h)
Impact Angle. . . . 13.7 deg
Speed at Parallel . 44.8 mi/h (72.1 km/h)
Exit Speed . . . . N/A
Exit Trajectory . . 0 deg
Vehicle Accelerations
  (Max. 0.050-sec Avg) at true c.g.
  Longitudinal. . . -1.9 g
  Lateral . . . . -2.9 g
Occupant Impact Velocity at true c.g.
  Longitudinal. . . 8.2 ft/s (2.5 m/s)
  Lateral . . . . 9.4 ft/s (2.9 m/s)
Occupant Ridedown Accelerations
  Longitudinal. . . -2.9 g
  Lateral . . . . -6.9 g
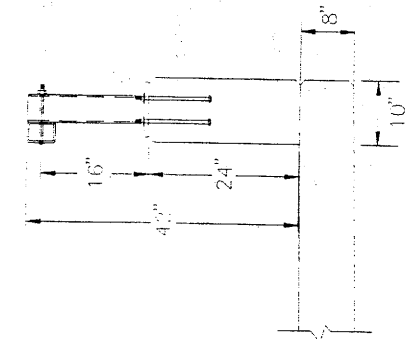
Figure 65. Summary of results for test 7069-26.

1 in = 25.4 mm

133

Table 25. Evaluation of crash test no. 7069-26.
{BR27C bridge railing on sidewalk [18,000 lb (8 172 kg)|51.0 mi/h (82.0 km/h)|13.7 degrees]}

	CRITERIA	TEST RESULTS	PASS/FAIL*
A.	Must contain vehicle	Vehicle was contained	Pass
B.	Debris shall not penetrate passenger compartment	No debris penetrated passenger compartment	Pass
C.	Passenger compartment must have essentially no deformation	No deformation	Pass
D.	Vehicle must remain upright	Vehicle did remain upright	Pass
E.	Must smoothly redirect the vehicle	Vehicle was smoothly redirected	Pass
F.	Effective coefficient of friction μ Assessment 0 - .25 Good .26 - .35 Fair > .35 Marginal	μ Assessment .40 (Impact @ curb) Marginal .14 (Impact @ rail) Good	Pass
G.	Shall be less than Occupant Impact Velocity - ft/s (m/s) Longitudinal Lateral 30 (9.2) 25 (7.6)	Occupant Impact Velocity - ft/s (m/s) Longitudinal Lateral 8.2 (2.5) 9.4 (2.9)	N/A
	Occupant Ridedown Accelerations - g's Longitudinal Lateral 15 15	Occupant Ridedown Accelerations - g's Longitudinal Lateral -2.9 -6.9	N/A
H.	Exit angle shall be less than 12 degrees	Exit angle was 0 degrees	Pass

*A, B, and C are required. D, E, F, and H are desired. G is not applicable for this test.(See table 1)

134

BR27C on Deck

Test Number 7069-32

Vehicle:	1983 Honda Civic
Test Inertia Weight:	1,800 lb (817 kg)
Gross Static Weight:	1,970 lb (894 kg)
Impact Speed:	60.3 mi/h (97.0 km/h)
Impact Angle:	19.8 deg

At 0.040 s after impact, the front of the vehicle began to deform to the right, and at 0.049 s the vehicle began to redirect. The roof of the vehicle began to deform at 0.084 s after impact. By 0.145 s the vehicle was traveling parallel to the bridge railing at a speed of 53.6 mi/h (86.2 km/h), and at 0.155 s the rear of the vehicle impacted the bridge railing. The vehicle lost contact with the bridge railing at 0.258 s traveling at 50.6 mi/h (81.4 km/h) and 6.6 degrees. The vehicle was in contact with the bridge railing for 9.9 ft (3.0 m). The brakes on the vehicle were applied at 1.4 s after impact and the vehicle subsequently came to rest 210 ft (64 m) down from and 120 ft (37 m) toward the traffic side of the point of impact.

The railing received minimal damage (figure 66). There was no deformation to the metal railing element.

The vehicle sustained damage to the right side (figure 66). Maximum crush at the right front corner at bumper height was 6.5 in (165 mm), and there was a 1.0-in (25-mm) dent into the occupant compartment at the fire wall. The passenger door was deformed outward approximately 1.3 in (33 mm) and the wheelbase on the right side was reduced 3.0 in (76 mm). An 8-in by 14-in by 7/16-in (203-mm by 356-mm by 11-mm) deep dent in the roof just over the right rear passenger location. The right front strut and sway bar were damaged and the instrument panel was bent. Also, damage was done to the front bumper, hood, grill, radiator, fan, right front quarter panel, right front rim, right door, right rear quarter panel, and right rear rim.

The railing contained the vehicle with no lateral movement of the railing. There was no intrusion of railing components into the occupant compartment although there was a 1-in (25-mm) dent into the occupant compartment at the fire wall. The vehicle remained upright and relatively stable during the collision. The bridge railing redirected the vehicle and the effective coefficient of friction was considered good. Velocity change of the vehicle during the collision was 9.7 mi/h (15.6 km/h). The occupant impact velocities and the occupant ridedown accelerations were within the limits. The vehicle trajectory at loss of contact indicated minimum intrusion into adjacent traffic lanes.

Performance of the railing in this test is judged acceptable, as indicated in figure 67 and table 26.
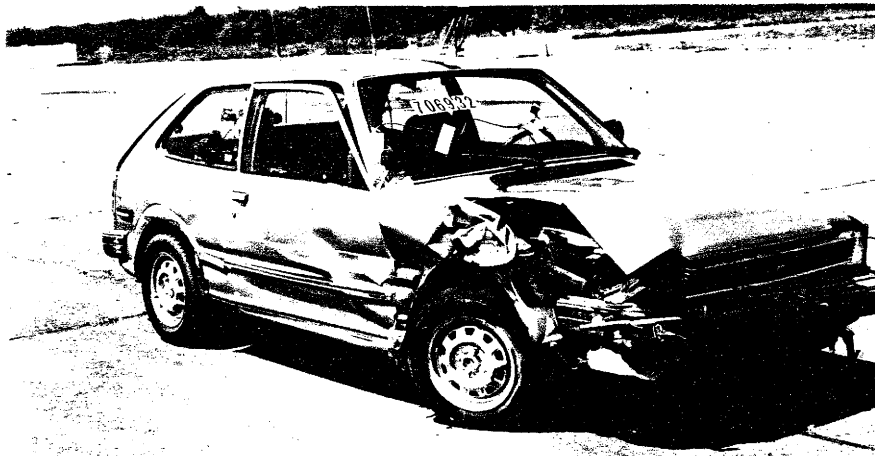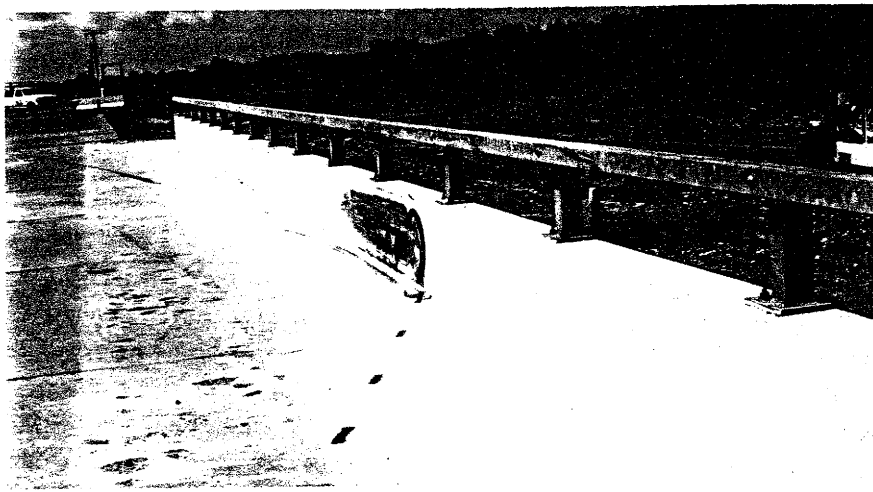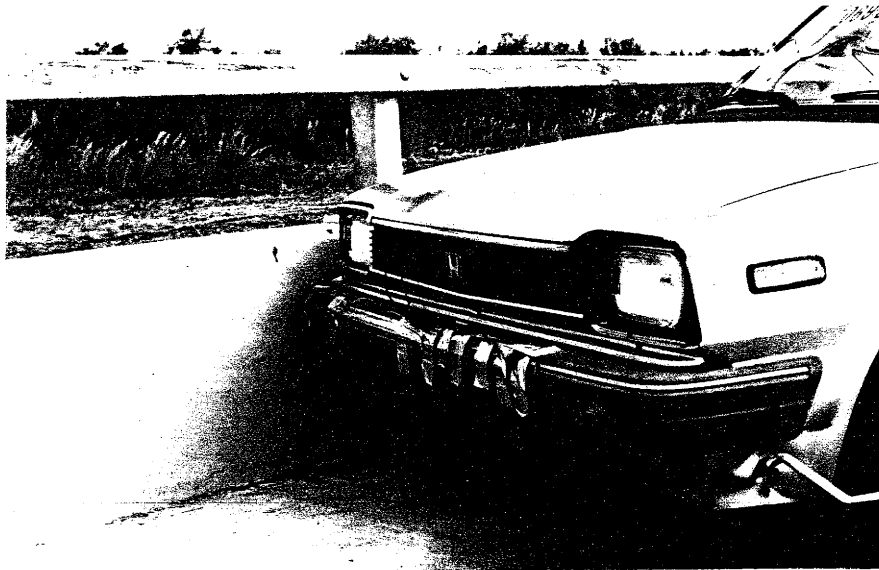
Figure 66. Vehicle and railing for test 7069-32.

137

0.000 s	0.074 s	
0.148 s	0.258 s	

Test No. . . . . : 7069-32
Date . . . . : 07/14/92
Test Installation . . . . BR27C Bridge Railing
                            on deck
Installation Length . . . 100 ft (30 m)

Test Vehicle . . . . 1983 Honda Civic
Vehicle Weight
    Test Inertia . . . . . 1,800 lb (817 kg)
    Gross Static . . . . . 1,970 lb (894 kg)
Vehicle Damage Classification
    TAD 01RFQ5
    CDC . . . . 01FREK3 & 01RYEW4
Maximum Vehicle Crush . . 6.5 in (165 mm)

Impact Speed. . . . . . 60.3 mi/h (97.0 km/h)
Impact Angle. . . . . . 19.8 deg
Speed at Parallel . . . 53.6 mi/h (86.2 km/h)
Exit Speed . . . . . . 50.6 mi/h (81.4 km/h)
Exit Trajectory . . . . 6.6 deg
Vehicle Accelerations
    (Max. 0.050-sec Avg) at true c.g.
    Longitudinal. . . . -5.7 g
    Lateral . . . . . . 12.2 g
Occupant Impact Velocity at true c.g.
    Longitudinal. . . . 14.5 ft/s (4.4 m/s)
    Lateral . . . . . . 24.6 ft/s (7.5 m/s)
Occupant Ridedown Accelerations
    Longitudinal . . . . -1.2 g
    Lateral . . . . . . 12.7 g

Figure 67. Summary of results for test 7069-32.

1 in = 25.4 mm

Table 26. Evaluation of crash test no. 7069-32.
{BR27C bridge railing on deck [1,800 lb (817 kg)|60.3 mi/h (97.0 km/h)|19.8 degrees]}

	CRITERIA	TEST RESULTS	PASS/FAIL*
A.	Must contain vehicle.	Vehicle was contained	Pass
B.	Debris shall not penetrate passenger compartment	No debris penetrated passenger compartment	Pass
C.	Passenger compartment must have essentially no deformation	Minimal deformation (1 in)	Pass
D.	Vehicle must remain upright	Vehicle did remain upright	Pass
E.	Must smoothly redirect the vehicle	Vehicle was smoothly redirected	Pass
F.	Effective coefficient of friction μ Assessment 0 - .25 Good .26 - .35 Fair > .35 Marginal	μ Assessment .15 Good	Pass
G.	Shall be less than Occupant Impact Velocity - ft/s (m/s) Longitudinal Lateral 30 (9.2) 25 (7.6) Occupant Ridedown Accelerations - g's Longitudinal Lateral 15 15	Occupant Impact Velocity - ft/s (m/s) Longitudinal Lateral 14.5 (4.4) 24.6 (7.5) Occupant Ridedown Accelerations - g's Longitudinal Lateral -1.2 12.7	Pass
H.	Exit angle shall be less than 12 degrees	Exit angle was 6.6 degrees	Pass

* A, B, C, D and G are required. E, F, and H are desired. (See table 1)

138

Vehicle: 1985 Chevrolet Pickup
Test Inertia Weight: 5,400 lb (2 452 kg)
Gross Static Weight: 5,570 lb (2 529 kg)
Impact Speed: 55.3 mi/h (89.0 km/h)
Impact Angle: 19.6 deg

At 0.022 s after impact the vehicle bumper began to ride up the barrier, and at 0.039 s the vehicle began to redirect. The bumper went between the concrete beam and lower metal railing element at 0.054 s, and at 0.083 the vehicle made contact with post 4. By 0.195 s the vehicle was traveling parallel to the bridge railing at a speed of 47.9 mi/h (77.1 km/h), and at 0.208 s the rear of the vehicle impacted the bridge railing. The vehicle lost contact with the bridge railing at 0.315 s traveling at 44.8 mi/h (72.1 km/h) and 6.5 degrees. The vehicle was in contact with the bridge railing for 11.0 ft (3.4 m). The brakes on the vehicle were applied at 1.7 s after impact and the vehicle subsequently came to rest 225 ft (68.6) down from and 5 ft (2 m) behind the point of impact.

The railing received minimal damage (figure 68). There was 0.5 in (13 mm) deformation to the lower metal railing element and there was a hairline crack in the concrete beam 17.5 in (445 mm) down from post 3.

The vehicle sustained damage to the right side (figure 68). Maximum crush at the right front corner at bumper height was 9.0 in (229 mm) and there was a 0.5-in (13-mm) dent into the occupant compartment at the fire wall. The wheelbase on the right side was reduced 2.0 in (51 mm). The sway bars were damaged and the frame was bent. Also, damage was done to the front bumper, hood, grill, radiator, fan, right front quarter panel, right front tire and rim, right door, right rear quarter panel, rear bumper, right rear rim, and left front quarter panel.

The railing contained the vehicle with no lateral movement of the railing. There was no intrusion of railing components into the occupant compartment although there was a 0.5-in (13-mm) dent into the occupant compartment at the fire wall. The vehicle remained upright and relatively stable during the collision. The bridge railing redirected the vehicle and the effective coefficient of friction was considered good. Velocity change of the vehicle during the collision was 10.5 mi/h (16.9 km/h). The occupant impact velocities and the occupant ridedown accelerations were within the limits. The vehicle trajectory at loss of contact indicated minimum intrusion into adjacent traffic lanes.

Performance of the railing in this test is judged acceptable, as indicated in figure 69 and table 27.
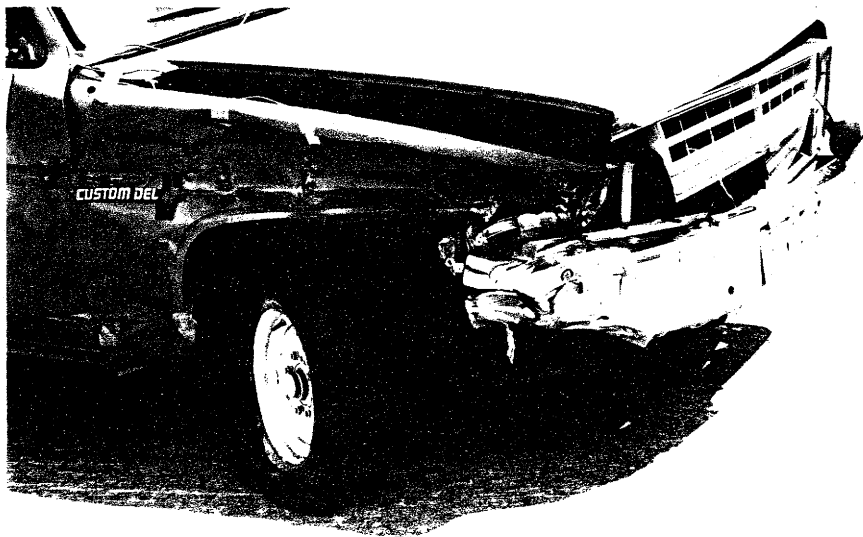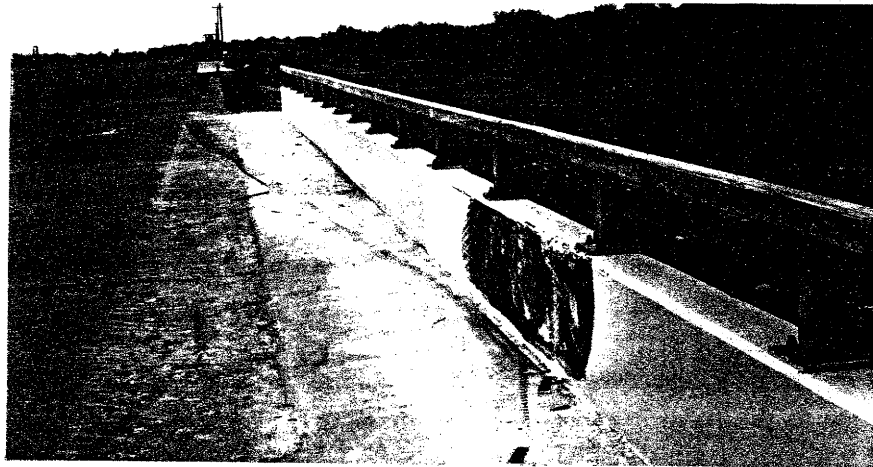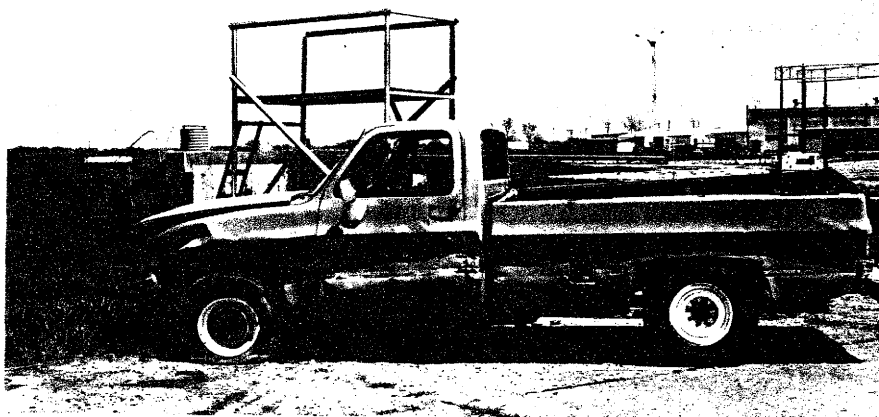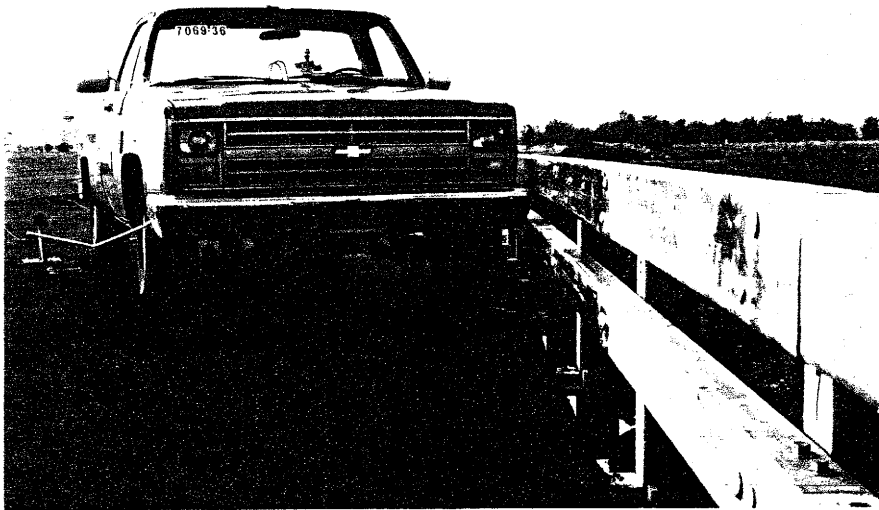
Figure 68. Vehicle and railing for test 7069-33.

140

0.000 s   0.088 s   0.176 s   0.315 s

Test No.	7069-33
Date	07/16/92
Test Installation	BR27C Bridge Railing on deck
Installation Length . .	100 ft (30 m)
Test Vehicle	1985 Chevrolet
Vehicle Weight	Pickup
Test Inertia	5,400 lb (2 452 kg)
Gross Static	5,570 lb (2 529 kg)
Vehicle Damage Classification	
TAD	01RFQ4 & 01RD2
CDC	01FREK2 & 01RDEW2
Maximum Vehicle Crush .	9.0 in (229 mm)
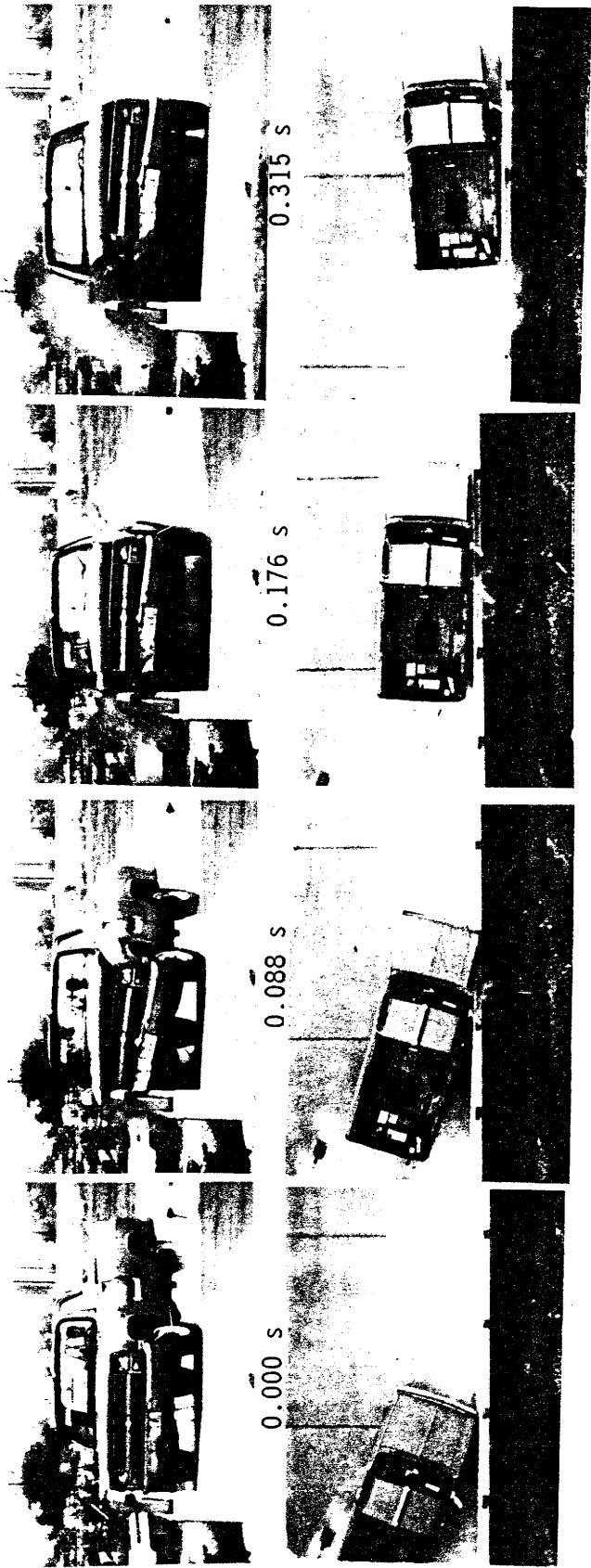
Impact Speed.	55.3 mi/h	(89.0 km/h)
Impact Angle.	19.6 deg	
Speed at Parallel . .	47.9 mi/h	(77.1 km/h)
Exit Speed	44.8 mi/h	(72.1 km/h)
Exit Trajectory . . .	6.5 deg	
Vehicle Accelerations		
(Max. 0.050-sec Avg) at true c.g.		
Longitudinal. . .	-4.9 g	
Lateral	9.3 g	
Occupant Impact Velocity at true c.g.		
Longitudinal. . .	11.6 ft/s	(3.5 m/s)
Lateral	20.1 ft/s	(6.1 m/s)
Occupant Ridedown Accelerations		
Longitudinal . . .	-2.2 g	
Lateral	8.1 g	
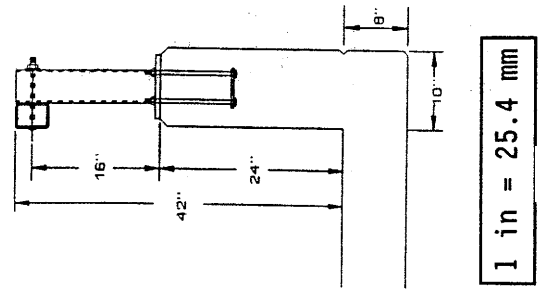
Figure 69. Summary of results for test 7069-33.

42" 16" 24" 8" 10"

1 in = 25.4 mm

Table 27. Evaluation of crash test no. 7069-33.
{BR27C bridge railing on deck [5,400 lb (2 452 kg)|55.3 mi/h (89.0 km/h)|19.6 degrees]}

	CRITERIA	TEST RESULTS	PASS/FAIL*
A.	Must contain vehicle	Vehicle was contained	Pass
B.	Debris shall not penetrate passenger compartment	No debris penetrated passenger compartment	Pass
C.	Passenger compartment must have essentially no deformation	Minimal deformation of 0.5 in	Pass
D.	Vehicle must remain upright	Vehicle did remain upright	Pass
E.	Must smoothly redirect the vehicle	Vehicle was smoothly redirected	Pass
F.	Effective coefficient of friction		Pass

F. Assessment:

μ	Assessment
0 - .25	Good
.26 - .35	Fair
> .35	Marginal

μ	Assessment
.23	Good

	CRITERIA	TEST RESULTS	PASS/FAIL*
G.	Shall be less than		Pass

G. Occupant Impact Velocity - ft/s (m/s)

Longitudinal	Lateral
30 (9.2)	25 (7.6)

Occupant Impact Velocity - ft/s (m/s)

Longitudinal	Lateral
11.6 (3.5)	20.1 (6.1)

Occupant Ridedown Accelerations - g's

Longitudinal	Lateral
15	15

Occupant Ridedown Accelerations - g's

Longitudinal	Lateral
-2.2	8.1

	CRITERIA	TEST RESULTS	PASS/FAIL*
H.	Exit angle shall be less than 12 degrees	Exit angle was 6.5 degrees	Pass

* A, B, C, and D are required. E, F, G, and H are desired. (See table 1)

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Vehicle:	1981 Ford Single-Unit Truck
Test Inertia Weight:	18,000 lb (8 172 kg)
Empty Weight:	10,490 lb (4 762 kg)
Impact Speed:	52.5 mi/h (84.5 km/h)
Impact Angle:	12.8 deg

As the vehicle impacted the bridge railing, the vehicle bumper began to ride up the concrete parapet. At 0.017 s after impact the right front wheel made contact with the concrete parapet, and at 0.072 s a significant clockwise steer input occurred. The bumper went between the concrete parapet and lower metal railing element at 0.094 s, and by 0.118 s the vehicle was traveling parallel to the bridge railing at a speed of 46.8 mi/h (75.3 km/h). At 0.174 the vehicle bumper made contact with post 6 and then contacted post 7 at 0.276 s. The vehicle lost contact with the bridge railing at approximately 0.811 s traveling at 44.6 mi/h (71.8 km/h) and 3.5 degrees. The brakes on the vehicle were applied at 1.9 s after impact and the vehicle subsequently came to rest 225 ft (68.6) from the point of impact. The vehicle was in contact with the bridge railing for 41.0 ft (12.5 m).

The railing received minimal damage with most being contained within the area around posts 4, 5, and 6. Cracking occurred in posts 4 and 5 in the heat affected zone in the posts at the post-to-baseplate connection. The crack occurred at the corners on the traffic side of the tubular steel element (corner of maximum stress) and extended approximately 1 in in both directions. There was a hairline crack in the concrete parapet in line with the rear post bolts at post 4. There was 1.5 in (38 mm) deformation to the metal railing element between posts 4 and 5.

The vehicle sustained damage mostly to the right side (figure 70). Maximum crush at the right front corner at bumper height was 28.0 in (711 mm). The steering arm, front springs and shackles, left front king pin and front axle were damaged and the frame was bent. Also, damage was done to the front bumper, right front quarter panel, right front tire and rim, right door, right rear outside tire and rim, gas tank and box-van.

The railing contained the vehicle with minimal lateral movement of the railing. There was no intrusion of railing components into the occupant compartment. The vehicle remained upright and relatively stable during the collision. The bridge railing redirected the vehicle and the effective coefficient of friction was considered marginal. Velocity change of the vehicle during the collision was 9.7 mi/h (15.6 km/h). The vehicle trajectory at loss of contact indicated minimum intrusion into adjacent traffic lanes.

Performance of the railing in this test is judged acceptable, as indicated in figure 71 and table 28.

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Figure 70. Vehicle and railing for test 7069-34.
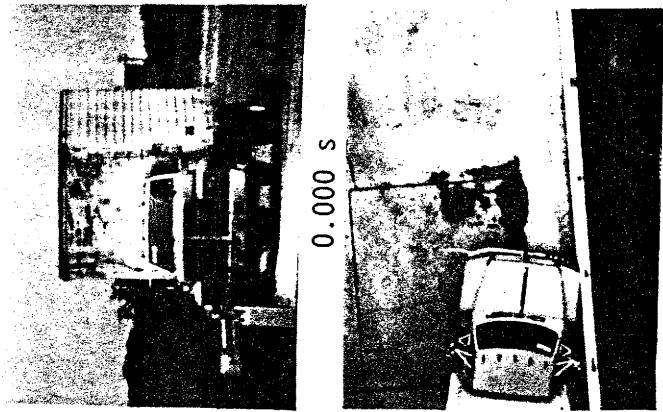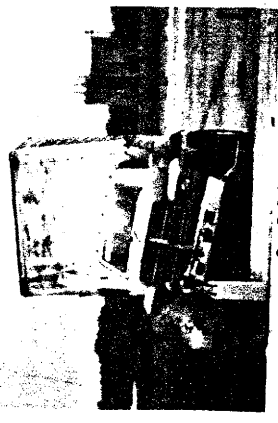
0.000 s	0.123 s	0.246 s	0.445 s
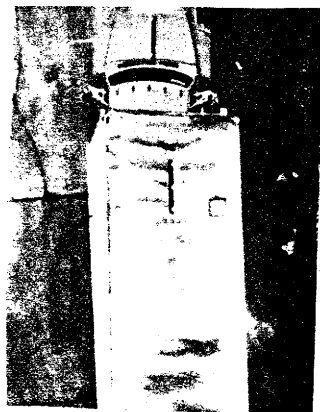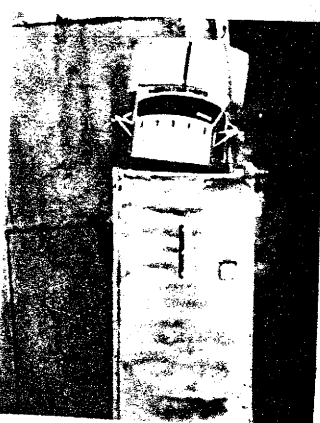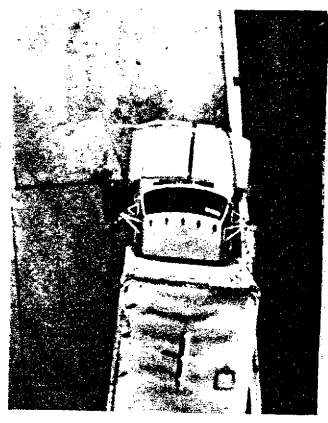
Test No. 7069-34
Date 08/12/92
Test Installation . . . . BR27C Bridge Railing
                          on deck
Installation Length . . . 100 ft (30 m)

Test Vehicle . . . . 1981 Ford
                          Single-Unit Truck
Vehicle Weight
  Empty Weight . . . . . . 10,490 lb (4 762 kg)
  Test Inertia . . . . . . 18,000 lb (8 172 kg)
Maximum Vehicle Crush . . 28.0 in (711 mm)

Max. Perm. Rail Deform.. 1.5 in (38 mm)

Impact Speed. . . . . . . 52.5 mi/h (84.5 km/h)
Impact Angle. . . . . . . 12.8 deg
Speed at Parallel . . . . 46.8 mi/h (75.3 km/h)
Exit Speed. . . . . 44.6 mi/h (71.8 km/h)
Exit Trajectory 3.5
Vehicle Accelerations
  (Max. 0.050-sec Avg) at c.g.
  Longitudinal. . . . . . -1.9 g
  Lateral . . . . 4.3 g
Occupant Impact Velocity at true c.g.
  Longitudinal. . . . . . 8.2 ft/s (2.5 m/s)
  Lateral . . . . 13.1 ft/s (4.0 m/s)
Occupant Ridedown Accelerations
  Longitudinal. . . . . . -1.1 g
  Lateral . . . . 5.2 g
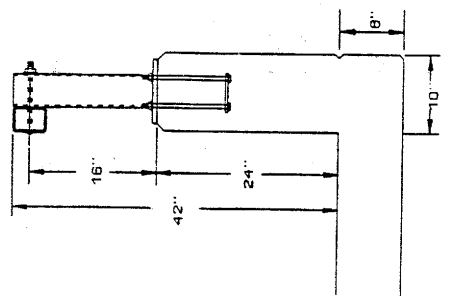
Figure 71. Summary of results for test 7069-34.

1 in = 25.4 mm

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Table 28. Evaluation of crash test no. 7069-34.
{BR27C bridge railing on deck [18,000 lb (8 172 kg)|52.5 mi/h (84.5 km/h)|12.8 degrees]}

	CRITERIA	TEST RESULTS	PASS/FAIL*
A.	Must contain vehicle	Vehicle was contained	Pass
B.	Debris shall not penetrate passenger compartment	No debris penetrated passenger compartment	Pass
C.	Passenger compartment must have essentially no deformation	No deformation	Pass
D.	Vehicle must remain upright	Vehicle remained upright during test.	N/A
E.	Must smoothly redirect the vehicle	Vehicle was smoothly redirected	N/A
F.	Effective coefficient of friction $\underline{\mu}$ $\underline{Assessment}$ 0 - .25 Good .26 - .35 Fair > .35 Marginal	$\underline{\mu}$ $\underline{Assessment}$ .38 Marginal	N/A
G.	Shall be less than $\underline{Occupant\ Impact\ Velocity}$ - ft/s (m/s) Longitudinal Lateral 30 (9.2) 25 (7.6) $\underline{Occupant\ Ridedown\ Accelerations}$ - g's Longitudinal Lateral 15 15	$\underline{Occupant\ Impact\ Velocity}$ - ft/s (m/s) Longitudinal Lateral 8.2 (2.5) 13.1 (4.0) $\underline{Occupant\ Ridedown\ Accelerations}$ - g's Longitudinal Lateral -1.1 4.3	N/A N/A
H.	Exit angle shall be less than 12 degrees	Exit angle was 3.5 degrees	N/A

* A, B, and C are required. D, E, F, and H are desired. (See table 1)

146

Illinois Side-Mounted Railing

Test Number 7069-35

Vehicle:	1981 Honda Civic
Test Inertia Weight:	1,800 lb (817 kg)
Gross Static Weight:	1,970 lb (894 kg)
Impact Speed:	59.9 mi/h (96.4 km/h)
Impact Angle:	20.1 deg

Upon impact the front bumper was pushed toward the passenger side of the vehicle and the bumper then separated from the vehicle on the passenger side. At 0.044 s after impact the vehicle began to redirect, and at 0.065 s the windshield began to crack at the lower corner on the driver side. The lower edge of the left front tire began to ride down the slope of the asphalt between the lower rail element and deck, and by 0.113 s the tire reached the lowest point under the rail element. By 0.136 s the vehicle was traveling parallel to the bridge railing at a speed of 51.1 mi/h (86.2 km/h), and at 0.148 s the rear of the vehicle impacted the bridge railing. By this time the left front tire was returning to the asphalt surface. The vehicle lost contact with the bridge railing at 0.190 s traveling at 50.8 mi/h (81.7 km/h) and 6.4 degrees. The vehicle was in contact with the bridge railing for 8.4 ft (2.6 m). The brakes on the vehicle were applied at 1.65 s after impact, the vehicle yawed clockwise and subsequently came to rest 150 ft (46 m) down from and 114 ft (35 m) in front of the point of impact.

The railing received minimal damage (figure 72). There was no deformation to the metal rail element.

The vehicle sustained damage to the left side (figure 72). Maximum crush at the left front corner at bumper height was 7.5 in (190 mm) and there was a 1.3-in (33-mm) dent into the occupant compartment at the fire wall. The driver door was deformed outward approximately 4.1 in (104 mm) and there was a small dent in the roof just above the B-pillar. The left front strut and sway bar were damaged, the instrument panel was bent, the windshield cracked, and the A-pillar was bent on the driver side. Also, damage was done to the front bumper, hood, grill, left front and rear quarter panel, left front and rear rim, and left door.

The railing contained the vehicle with no lateral movement of the railing. There was no intrusion of railing components into the occupant compartment although there was a 1.3-in (33-mm) dent into the occupant compartment at the fire wall. The vehicle remained upright and relatively stable during the collision. The bridge railing redirected the vehicle and the effective coefficient of friction was considered good. Velocity change of the vehicle during the collision was 9.1 mi/h (14.6 km/h). The longitudinal occupant impact velocity and the occupant ridedown accelerations were within the limits, however the lateral impact velocity of 25.8 ft/s was considered marginal. The vehicle trajectory at loss of contact indicated minimum intrusion into adjacent traffic lanes.

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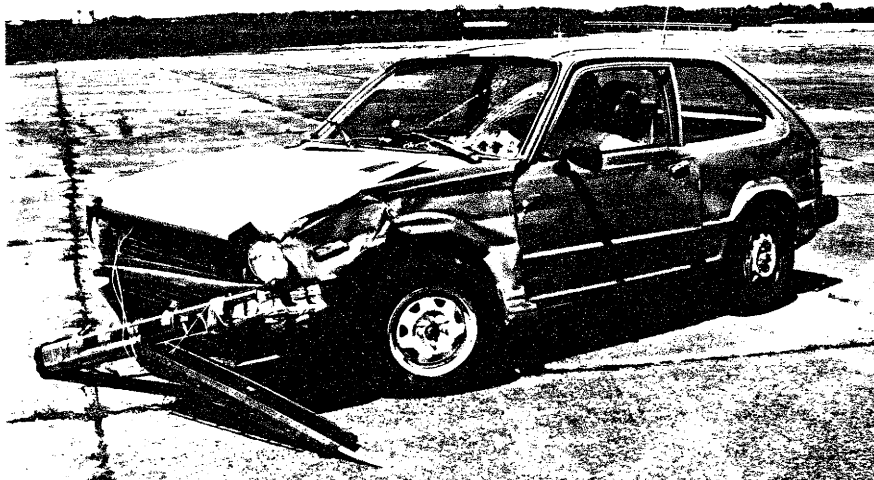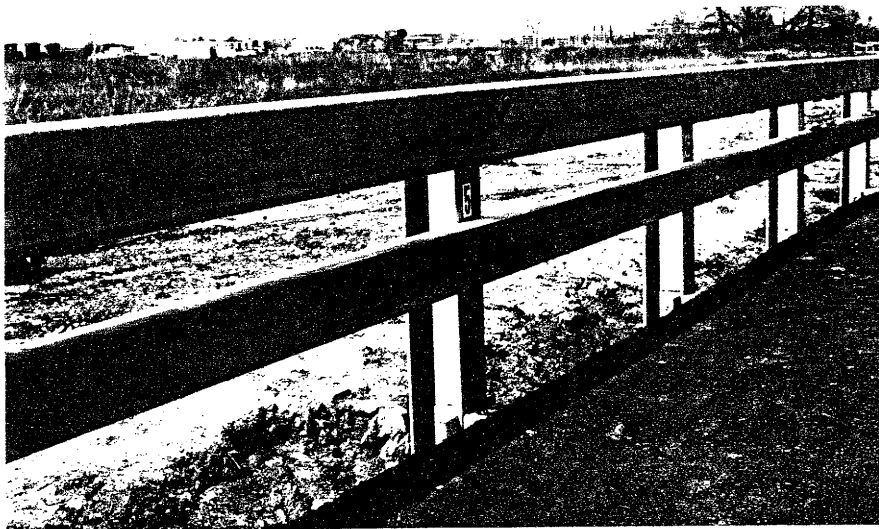
Figure 72. Vehicle and railing for test 7069-35.

Performance of the railing in this test is judged acceptable, as indicated in figure 73 and table 29.
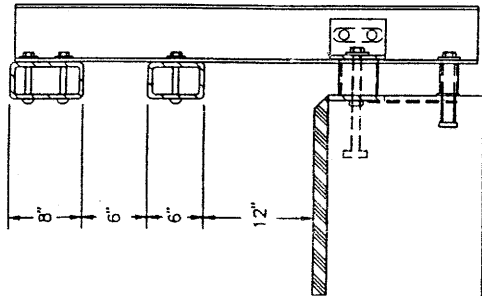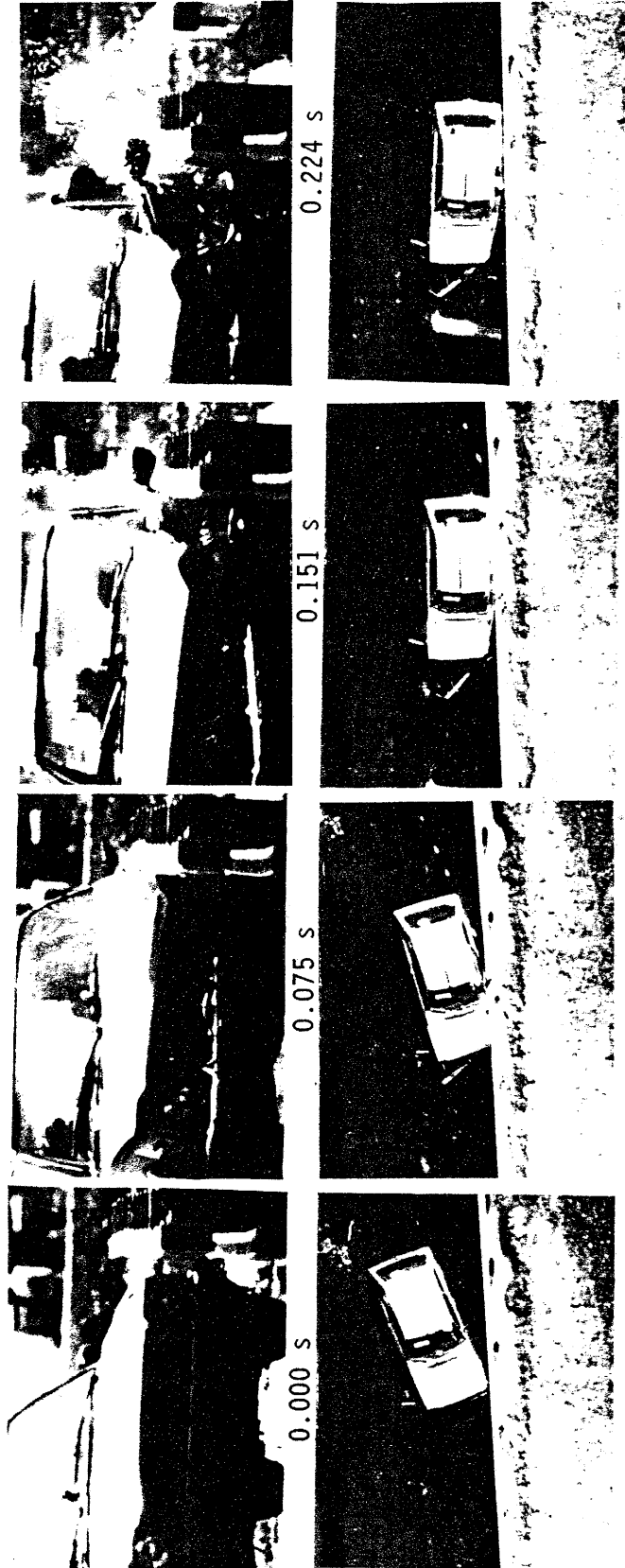
Test No.	7069-35
Date	03/23/93
Test Installation	Illinois Side Mount
	Bridge Railing
Installation Length . .	84 ft (26 m)
Test Vehicle	1981 Honda Civic
Vehicle Weight	
Test Inertia	1,800 lb (817 kg)
Gross Static	1,970 lb (894 kg)
Vehicle Damage Classification	
TAD	11FL3 & 11LD3
CDC	11FLEK2 & 11LDEW3
Maximum Vehicle Crush	7.5 in (190 mm)

Impact Speed.	59.9 mi/h (96.4 km/h)
Impact Angle.	20.1 deg
Speed at Parallel . . .	51.1 mi/h (82.2 km/h)
Exit Speed	50.8 mi/h (81.7 km/h)
Exit Trajectory	6.4 deg
Vehicle Accelerations	
(Max. 0.050-sec Avg) at true c.g.	
Longitudinal.	-6.4 g
Lateral	-14.8 g
Occupant Impact Velocity at true c.g.	
Longitudinal.	15.9 ft/s (4.8 m/s)
Lateral	25.8 ft/s (7.9 m/s)
Occupant Ridedown Accelerations	
Longitudinal	-1.7 g
Lateral	-6.6 g

Figure 73. Summary of results for test 7069-35.

1 in = 25.4 mm

Table 29. Evaluation of crash test no. 7069-35.
{Illinois Side Mounted Bridge Railing [1,800 lb (817 kg)|59.9 mi/h (96.4 km/h)|20.1 degrees]}

	CRITERIA	TEST RESULTS	PASS/FAIL*
A.	Must contain vehicle	Vehicle was contained	Pass
B.	Debris shall not penetrate passenger compartment	No debris penetrated passenger compartment	Pass
C.	Passenger compartment must have essentially no deformation	Minimal deformation (1.3 in)	Pass
D.	Vehicle must remain upright	Vehicle did remain upright	Pass
E.	Must smoothly redirect the vehicle	Vehicle was smoothly redirected	Pass
F.	Effective coefficient of friction μ Assessment 0 - .25 Good .26 - .35 Fair > .35 Marginal	μ Assessment .25 Good	Pass
G.	Shall be less than Occupant Impact Velocity - ft/s (m/s) Longitudinal Lateral 30 (9.2) 25 (7.6) Occupant Ridedown Accelerations - g's Longitudinal Lateral 15 15	Occupant Impact Velocity - ft/s (m/s) Longitudinal Lateral 15.9 (4.8) 25.8 (7.9) Occupant Ridedown Accelerations - g's Longitudinal Lateral -1.7 -6.6	Marginal Pass
H.	Exit angle shall be less than 12 degrees	Exit angle was 6.4 degrees	Pass

* A, B, C, D and G are required. E, F, and H are desired. (See table 1)

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Vehicle:	1986 Chevrolet Pickup
Test Inertia	5,400 lb (2 452 kg)
Gross Static Weight:	5,565 lb (2 526 kg)
Impact Speed:	60.4 mi/h (97.2 km/h)
Impact Angle:	20.4 deg

At 0.017 s after impact, the left front tire contacted the lower rail element and at 0.027 s the vehicle began to redirect. At 0.036 s the left front wheel redirected and the tire began to ride along the edge of the asphalt slope on the bridge deck. The dummy's shoulder impacted the door of the vehicle at 0.080 s and the door glass shattered at 0.107 s. By 0.182 s the vehicle was traveling parallel to the bridge railing at a speed of 56.6 mi/h (91.1 km/h), and at 0.189 s the rear of the vehicle contacted the bridge railing. The vehicle lost contact with the bridge railing at 0.291 s traveling at 55.6 mi/h (89.5 km/h) and 9.0 degrees. The vehicle was in contact with the bridge railing for 14.8 ft (4.5 m). The brakes on the vehicle were applied at 1.4 s after impact. One of the rear wheels locked up causing the vehicle to yaw counter-clockwise into a protective barrier, and it subsequently came to rest 330 ft (100 m) down from and 16 ft (5 m) toward the field side of the point of impact.

The railing received moderate damage (figure 74). There was 1.0 in (25 mm) deformation to the upper rail element and 0.75 in (19 mm) to the lower rail element near post 5. The flanges on posts 4 and 5 were deformed just above the angles (L6x4x1/4x4) and these angles were bent.

The vehicle sustained damage to the left side. Maximum crush at the left front corner at bumper height was 13.0 in (330 mm) and there was a 0.4-in (10-mm) dent into the occupant compartment at the fire wall and center tunnel. The frame was bent and the door on the driver side was deformed outward 3.2 in (81 mm). Also, damage was done to the front bumper, hood, grill, radiator, fan, left front quarter panel, left front tire and rim, left door, left rear quarter panel, rear bumper, and left rear rim. Most of the damage to the right side of the vehicle was sustained when the vehicle impacted the protective barrier.

The railing contained the vehicle with minimal lateral movement of the railing. There was no intrusion of railing components into the occupant compartment although there was a 0.4-in (10-mm) dent into the occupant compartment at the fire wall. The vehicle remained upright and relatively stable during the collision. The railing redirected the vehicle and the effective coefficient of friction was considered good. Velocity change of the vehicle during the collision was 4.8 mi/h (7.7 km/h). The occupant impact velocities and the occupant ridedown accelerations were within the limits. The vehicle trajectory at loss of contact indicated minimum intrusion into adjacent traffic lanes.

Performance of the railing in this test is judged acceptable, as indicated in figure 75 and table 30.

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Figure 74. Vehicle and railing for test 7069-36.

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Test No.	7069-36
Date	03/25/93
Test Installation	Illinois Side Mount Bridge Railing
Installation Length . .	84 ft (26 m)
Test Vehicle	1985 Chevrolet Pickup
Vehicle Weight	
Test Inertia	5,400 lb (2 452 kg)
Gross Static	5,565 lb (2 526 kg)
Vehicle Damage Classification	
TAD	11FL4 & 11LD4
CDC	11FLEK3 & 11LDEW3
Maximum Vehicle Crush .	13.0 in (330 mm)
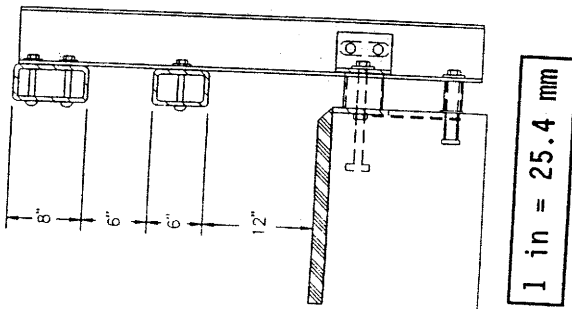
Impact Speed.	60.4 mi/h (97.2 km/h)
Impact Angle.	20.4 deg
Speed at Parallel . .	56.6 mi/h (91.1 km/h)
Exit Speed	55.6 mi/h (89.5 km/h)
Exit Trajectory . . .	9.0 deg
Vehicle Accelerations	
(Max. 0.050-sec Avg) at true c.g.	
Longitudinal. . . .	-4.1 g
Lateral	-12.0 g
Occupant Impact Velocity at true c.g.	
Longitudinal. . . .	11.7 ft/s (3.6 m/s)
Lateral	24.4 ft/s (7.4 m/s)
Occupant Ridedown Accelerations	
Longitudinal . . .	1.0 g
Lateral	-12.3 g

1 in = 25.4 mm

Figure 75. Summary of results for test 7069-36.

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Table 30. Evaluation of crash test 7069-36.
{Illinois Side Mounted Bridge Railing [5,400 lb (2 452 kg)|60.4 mi/h (97.2 km/h)|20.4 degrees]}

	CRITERIA	TEST RESULTS	PASS/FAIL*
A.	Must contain vehicle	Vehicle was contained	Pass
B.	Debris shall not penetrate passenger compartment	No debris penetrated passenger compartment	Pass
C.	Passenger compartment must have essentially no deformation	Minimal deformation of 0.4 in	Pass
D.	Vehicle must remain upright	Vehicle did remain upright	Pass
E.	Must smoothly redirect the vehicle	Vehicle was smoothly redirected	Pass
F.	Effective coefficient of friction μ Assessment 0 - .25 Good .26 - .35 Fair > .35 Marginal	μ Assessment .00 Good	Pass
G.	Shall be less than Occupant Impact Velocity - ft/s (m/s) Longitudinal Lateral 30 (9.2) 25 (7.6) Occupant Ridedown Accelerations - g's Longitudinal Lateral 15 15	Occupant Impact Velocity - ft/s (m/s) Longitudinal Lateral 11.7 (3.6) 24.4 (7.4) Occupant Ridedown Accelerations - g's Longitudinal Lateral 1.0 -12.3	Pass Pass
H.	Exit angle shall be less than 12 degrees	Exit angle was 9.0 degrees	Pass

* A, B, C, and D are required. E, F, G, and H are desired. (See table 1)

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Vehicle:	1981 Ford Single-Unit Truck
Test Inertia Weight:	18,000 lb (8 172 kg)
Empty Weight:	10,810 lb (4 908 kg)
Impact Speed:	51.4 mi/h (82.7 km/h)
Impact Angle:	14.7 deg

Approximately 0.022 s after impact, the left front tire of the vehicle impacted the bridge railing and then rode up and steered into the rail. The vehicle began to redirect at 0.061 s, and by 0.261 s the vehicle was traveling parallel to the bridge railing at a speed of 46.8 mi/h (75.3 km/h). The rear of the vehicle contacted the bridge railing at approximately 0.283 s and the lower edge of the box-van set down on top of the rail at 0.331 s. It rode along in this manner until the vehicle exited the rail. The cab of the vehicle reached a maximum roll angle of about 12 degrees at 0.469 s. At 0.725 s the box-van had rolled to a maximum of about 53 degrees, and at 0.822 s began to right itself. The vehicle rode off the end of the bridge railing and the vehicle subsequently came to rest 165 ft (50 m) down from and 9 ft (3 m) toward the field side of the point of impact. The vehicle was in contact with the bridge railing for 69 ft (21 m).

The railing received moderate damage with most contained within the area between posts 4 through 7. The upper and lower rails sustained gouges between posts 4 and 5 from the lug nuts of the vehicle's wheel. The head of the lower bolt on the top rail at post 5 was torn off and the bolts on the lower element were loose. The angles at post 4 were slightly bent and those at posts 5 and 6 were deformed. The spacers at posts 4 and 5 were knocked loose and down. There was 2.5 in (64 mm) deformation to the upper rail element at post 5.

The vehicle sustained damage mostly to the left side (figure 76). Maximum crush at the left front corner at bumper height was 8.0 in (203 mm). The front springs, shackles, and U-bolt were damaged and the box-van shifted off the frame approximately 6 in (150 mm). Also, damage was done to the front bumper, left front quarter panel, left front tire and rim, left rear outside tire and rim, and lower edge of the box-van.

The railing contained the vehicle with minimal lateral movement of the railing. There was no intrusion of railing components into the occupant compartment. The vehicle remained upright and relatively stable during the collision. The bridge railing redirected the vehicle and the effective coefficient of friction was considered good. The vehicle trajectory at loss of contact indicated no intrusion into adjacent traffic lanes.

Performance of the railing in this test is judged acceptable, as indicated in figure 77 and table 31.
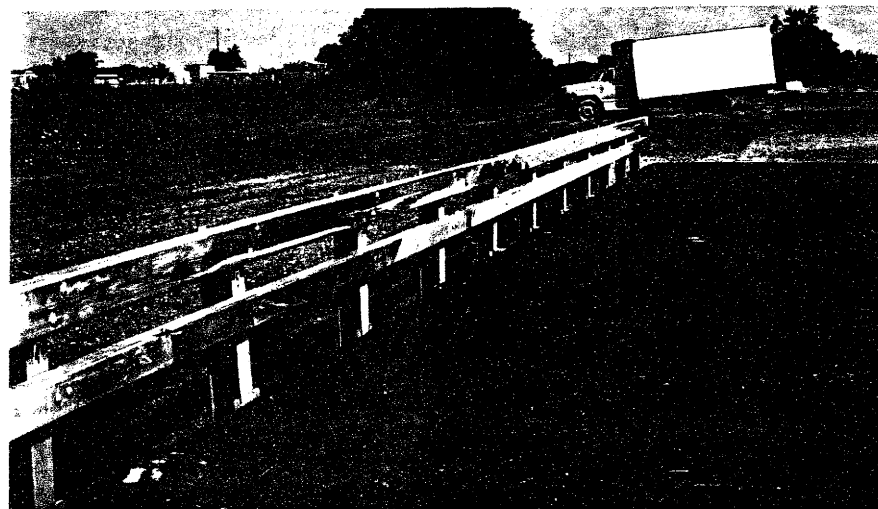
Figure 76. Vehicle and railing for test 7069-37.

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0.000 s	0.136 s
0.271 s	0.475 s
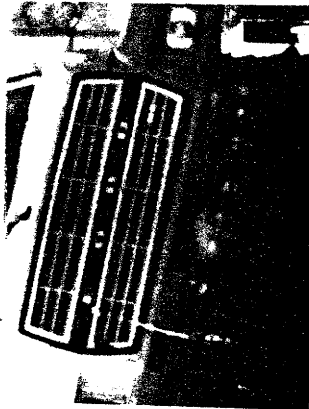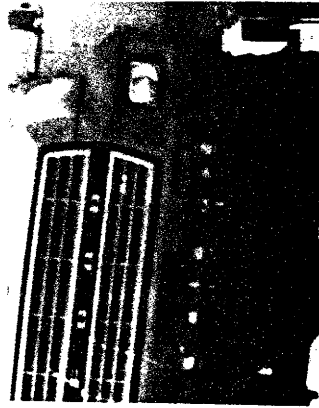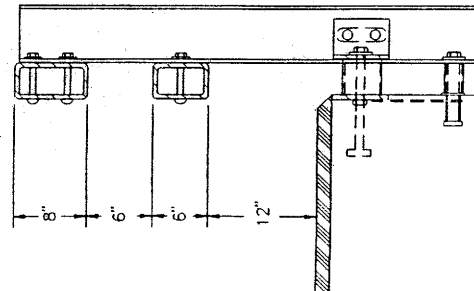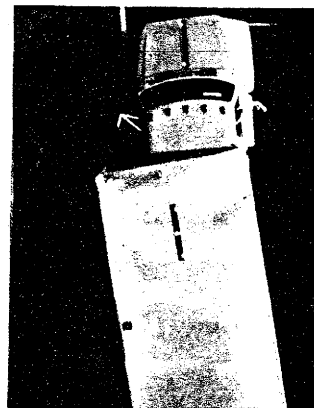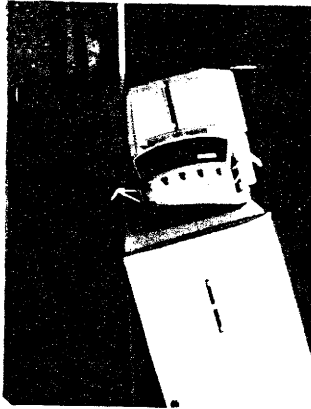
Test No. . . . . : 7069-37
Date . . . . : 04/30/93
Test Installation . . . . : Illinois Side Mount
                   Bridge Railing
Installation Length . . . : 84 ft (26 m)

Test Vehicle . . . . : 1981 Ford
                   Single-Unit Truck
Vehicle Weight
   Empty Weight . . . . . : 10,810 lb (4 908 kg)
   Test Inertia . . . . . : 18,000 lb (8 172 kg)
Maximum Vehicle Crush . . : 8.0 in (203 mm)

Max. Perm. Deform. . . . : 2.5 in (64 mm)

Impact Speed. . . . . : 51.4 mi/h (82.7 km/h)
Impact Angle. . . . . : 14.7 deg
Speed at Parallel . . : 46.8 mi/h (75.3 km/h)
Exit Speed . . . . . : N/A
Exit Trajectory . . . : N/A (behind rail)
Vehicle Accelerations
   (Max. 0.050-sec Avg) at c.g.
   Longitudinal. . . . : -1.5 g
   Lateral . . . . . : -3.8 g
Occupant Impact Velocity at true c.g.
   Longitudinal. . . . : 9.1 ft/s (2.8 m/s)
   Lateral . . . . . : 9.7 ft/s (3.0 m/s)
Occupant Ridedown Accelerations
   Longitudinal. . . . : -4.3 g
   Lateral . . . . . : -6.3 g

Figure 77. Summary of results for test 7069-37.

1 in = 25.4 mm

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Table 31. Evaluation of crash test no. 7069-37.
{Illinois Side Mounted Bridge Railing [18,000 lb (8 172 kg)|51.4 mi/h (82.7 km/h)|14.7 degrees]}

	CRITERIA	TEST RESULTS	PASS/FAIL*
A.	Must contain vehicle	Vehicle was contained	Pass
B.	Debris shall not penetrate passenger compartment	No debris penetrated passenger compartment	Pass
C.	Passenger compartment must have essentially no deformation	No deformation	Pass
D.	Vehicle must remain upright	Vehicle remained upright during test.	N/A
E.	Must smoothly redirect the vehicle	Vehicle was smoothly redirected	N/A
F.	Effective coefficient of friction _μ_ Assessment 0 - .25 Good .26 - .35 Fair > .35 Marginal	_μ_ Assessment .22 Good	N/A
G.	Shall be less than		
	Occupant Impact Velocity - ft/s (m/s) Longitudinal Lateral 30 (9.2) 25 (7.6)	Occupant Impact Velocity - ft/s (m/s) Longitudinal Lateral 9.1 (2.8) 9.7 (3.0)	N/A
	Occupant Ridedown Accelerations - g's Longitudinal Lateral 15 15	Occupant Ridedown Accelerations - g's Longitudinal Lateral -4.3 -6.3	N/A
H.	Exit angle shall be less than 12 degrees	Vehicle exited beind installation	N/A

* A, B, and C are required. D, E, F, and H are desired. (See table 1)

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PERFORMANCE LEVEL THREE RAILINGS

Two railing designs, as shown in table 32, were subjected to strength tests for performance level three.

The 42-in (1.07-m) vertical-faced concrete parapet was tested with a 50,000-lb (22 700-kg) tractor-trailer. Acceptable performance was obtained.

The 42-in (1.07-m) F-shape was tested with a 40,000-lb (18 160-kg) intercity bus because that was the proposed test vehicle at the time. The railing was then tested with a 50,000-lb (22 700-kg) tractor-trailer. Performance was acceptable in both tests.

Table 32. Summary of full-scale crash tests performed on performance level three railings.

RAILING DESIGN	TEST NO.	TEST DATE	ACTUAL CONDITIONS	DESIGN CONDITIONS	COMMENTS
42-in (1.07-m) PARAPET	7069-13	7/11/88	50,050 lb|51.4 mi/h|16.2 deg (22 723 kg|82.7 km/h|16.2 deg)	50,000 lb|50 mi/h|15 deg (22 700 kg|80.5 km/h|15 deg)	Acceptable
42-in (1.07-m) F-SHAPE	7069-7	11/19/87	40,560 lb|55.7 mi/h|15.7 deg (18 414 kg|89.6 km/h|15.7 deg)	40,000 lb|60 mi/h|15 deg (18 160 kg|96.5 km/h|15 deg)	Acceptable
	7069-10	3/3/88	50,000 lb|52.2 mi/h|14.0 deg (22 700 kg|84.0 km/h|14.0 deg)	50,000 lb|50 mi/h|15 deg (22 700 kg|80.5 km/h|15 deg)	Acceptable

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42-in (1.07-m) Concrete Parapet - Test Number 7069-13

Vehicle:	Tractor/Trailer
Test Inertia Weight:	50,050 lb (22 723 kg)
Empty Weight:	27,690 lb (12 571 kg)
Impact Speed:	51.4 mi/h (82.7 km/h)
Impact Angle:	16.2 deg

The vehicle impacted the parapet at 24 ft (7.3 m) from the upstream end. At approximately 0.010 s after impact, the right front wheel contacted the parapet, and the left front wheel became airborne at 0.135 s. The right front corner of the trailer contacted the parapet at about 0.178 s. The tractor began to redirect at 0.178 s, and the trailer began to redirect at 0.280 s. The rear wheels of the tractor lost contact with the pavement at 0.285 s, and left rear wheels of the trailer became airborne at 0.349 s. The left side of the tractor remained airborne until 0.417 s when the left front wheel touched down. The right rear trailer wheels contacted the parapet at about 0.684 s. The vehicle attained maximum roll to the right at about 1.165 s and began to roll left. The vehicle rode against the parapet and off the end. The brakes were applied, and the vehicle came to rest on its left side approximately 181 ft (55 m) downstream from the point of impact.

The parapet received only cosmetic damage (figure 78). There were tire marks on the parapet from just before the impact point extending a total of 85 ft (26 m) along the face. There was also a piece of the top of the parapet chipped off.

The vehicle sustained extensive damage to the right side. Maximum crush at the right front corner at bumper height was 18.0 in (457 mm). There was damage to the front axle, Pittman arm, U-bolts, front leaf springs and bolts, front shock mounts, air brake lines, right fuel cell, left rear spring pin and clamp, and exhaust pipe. The cab and left door were bent.

The parapet contained and redirected the vehicle with no lateral movement of the parapet. There were no debris or detached elements. There was no intrusion into the occupant compartment, although some deformation of the right door occurred. The vehicle trajectory at loss of contact indicated minimum intrusion into adjacent traffic lanes; however, the vehicle did not remain upright after the collision.

Performance of the parapet in this test is judged acceptable, as indicated in figure 79 and table 33.

This was the only test performed on the 42-in (1.07-m) concrete parapet.

162
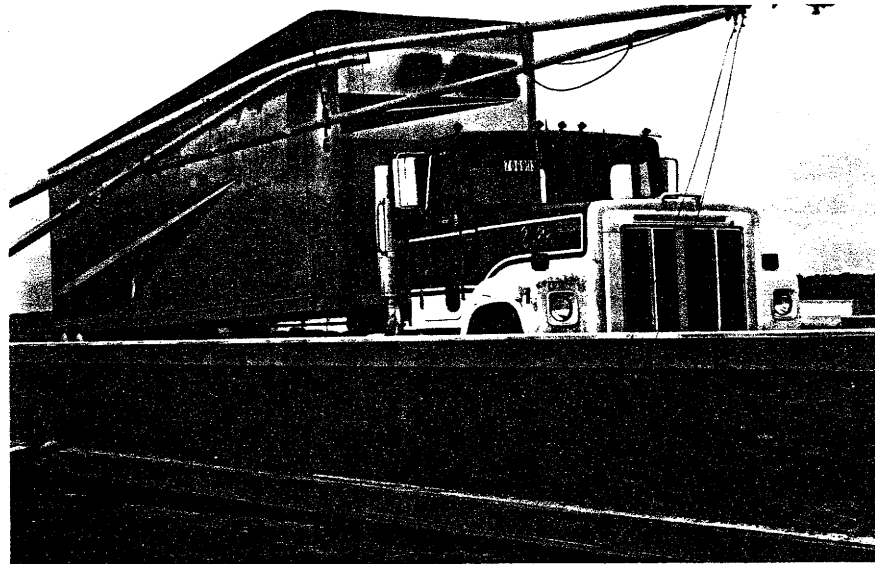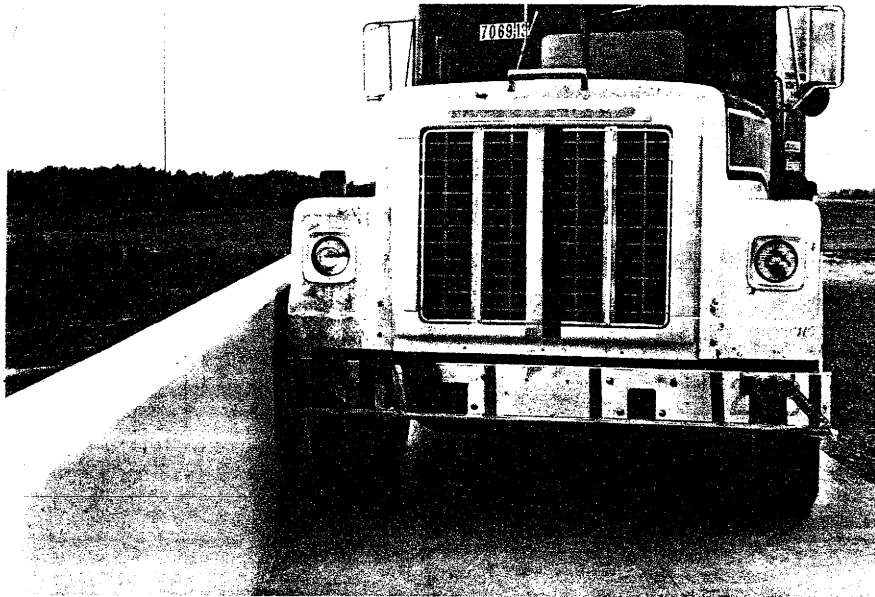
Figure 78. Vehicle and parapet for test 7069-13.

163
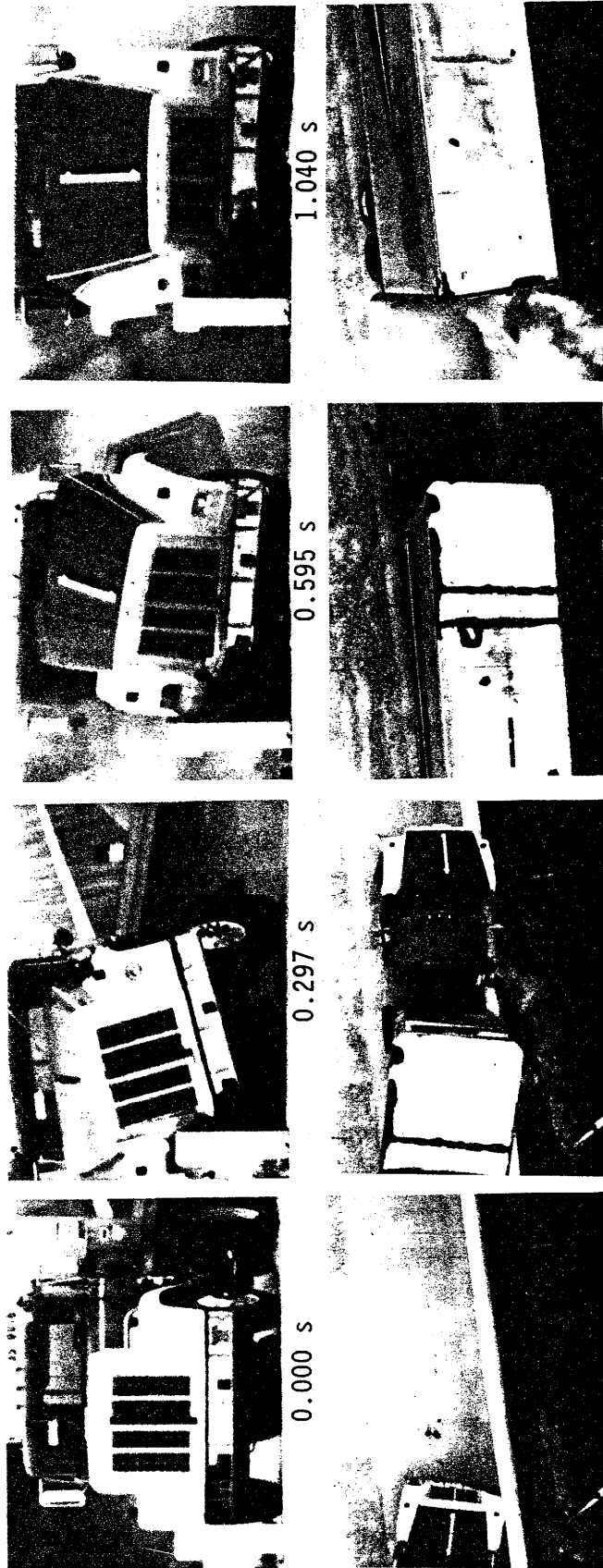
Test No.	7069-13	
Date	7/11/88	
Test Installation	42-in (1.07-m)	
	Concrete Parapet	
Installation Length. . . .	100 ft (30 m)	
Vehicle	1979 International	
	Tractor w/van-trailer	
Vehicle Weight		
Empty Weight	27,690 lb (12 571 kg)	
Test Inertia	50,050 lb (22 723 kg)	
Maximum Vehicle Crush . .	18.0 in (457 mm)	

Impact Speed. . . . 51.4 mi/h (82.7 km/h)
Impact Angle. . . . 16.2 deg
Exit Speed. . . . N/A
Exit Trajectory . 0.0 deg
Vehicle Accelerations
  (Max. 0.050-sec Avg)
  Longitudinal. . -3.3 g
  Lateral . . . 3.7 g
Occupant Impact Velocity
  Longitudinal. . 10.5 ft/s (3.2 m/s)
  Lateral . . . 12.5 ft/s (3.8 m/s)
Occupant Ridedown Accelerations
  Longitudinal. . -2.2 g
  Lateral . . . 4.6 g
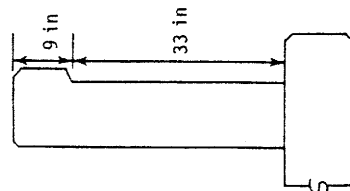
Figure 79. Summary of results for test 7069-13.

1 in = 25.4 mm

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Table 33. Evaluation of crash test no. 7069-13.
{42-in (1.07 m) Concrete Parapet [50,050 lb (22 723 kg)|51.4 mi/h (82.7 km/h)|16.2 degrees]}

	CRITERIA	TEST RESULTS	PASS/FAIL*
A.	Must contain vehicle	Vehicle was contained	Pass
B.	Debris shall not penetrate passenger compartment	No debris penetrated passenger compartment	Pass
C.	Passenger compartment must have essentially no deformation	Acceptable deformation	Pass
D.	Vehicle must remain upright	Vehicle did not remain upright	Fail
E.	Must smoothly redirect the vehicle	Vehicle was smoothly redirected	Pass
F.	Effective coefficient of friction		
	μ Assessment 0 - .25 Good .26 - .35 Fair > .35 Marginal	μ Assessment 0.55 Marginal	Pass
G.	Shall be less than		
	Occupant Impact Velocity - ft/s (m/s) Longitudinal Lateral 30 (9.2) 25 (7.6)	Occupant Impact Velocity - ft/s (m/s) Longitudinal Lateral 10.5 (3.2) 12.5 (3.8)	N/A
	Occupant Ridedown Accelerations - g's Longitudinal Lateral 15 15	Occupant Ridedown Accelerations - g's Longitudinal Lateral -2.2 4.6	N/A
H.	Exit angle shall be less than 12 degrees	about 0 degrees	Pass

* A, B, C, are required. D, E, F, and H are desired. G is not applicable for this test. (See table 1)

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42-in (1.07-m) F-Shape

Test Number 7069-7

Vehicle:	1954 GMC Scenicruiser Bus
Test Inertia Weight:	40,560 lb (18 414 kg)
Empty Weight:	29,840 lb (13 547 kg)
Impact Speed:	55.7 mi/h (89.6 km/h)
Impact Angle:	15.7 deg

The vehicle impacted the bridge railing at 35 ft (10.1 m) from the upstream end. At approximately 0.035 s after impact the right front wheel contacted the bridge railing. The vehicle began to redirect at 0.098 s as the rear end began to slide toward the bridge railing. The rear of the vehicle slapped the bridge railing at 0.3872 s, and by 0.396 s the vehicle was traveling parallel with the bridge railing. The vehicle very briefly lost contact with the bridge railing and contacted it again. The vehicle rode against the bridge railing and off the end. The brakes were applied and the vehicle subsequently came to rest approximately 250 ft (76 m) downstream and 40 ft (12 m) on the field side of the point of impact.

The railing received only cosmetic damage (figure 80). There were tire marks on the bridge railing from just before the impact point extending a total of 25 ft (7.6 m) along the face. The vehicle then lost contact for 26 ft (7.9 m) and contacted the bridge railing for another 21 ft (6.4 m) when the bridge railing ended. There was also a longitudinal hairline crack along the bridge deck starting approximately at the point of impact for about 35 ft (11 m) running parallel to and nominally 2 ft (0.6 m) from the base of the railing.

The vehicle sustained extensive damage to the right side. Maximum crush at the right front corner at bumper height was 4.0 in (102 mm). The right front and right rear wheel rims were scratched. The front wheel assembly and suspension was damaged. The door was bent and the windshield was broken out. The right rear panel was dented and scraped.

The railing contained and smoothly redirected the vehicle with no lateral movement of the railing. There were no debris or detached elements. There was no intrusion into the occupant compartment although some deformation of the right door occurred. The vehicle trajectory at loss of contact indicated minimum intrusion into adjacent traffic lanes. The vehicle remained upright and stable during the entire test period.

Performance of the railing in this test is judged acceptable, as indicated in figure 81 and table 34.

166
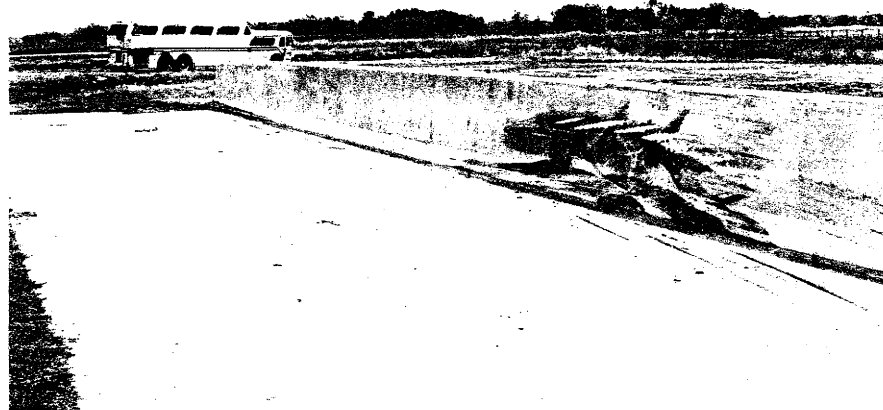
Figure 80. Vehicle and parapet for test 7069-7.

0.000 s	0.192 s	0.384 s	0.576 s
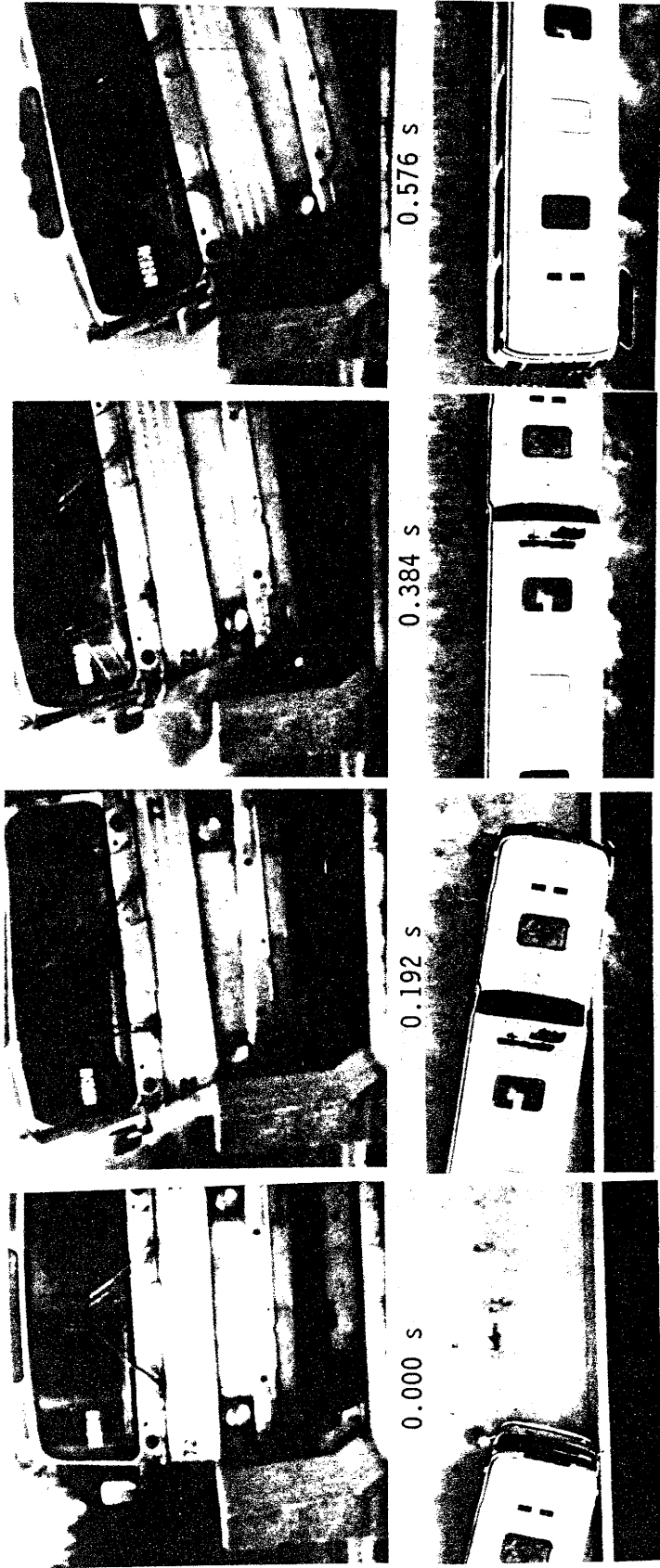
Test No. 7069-7
Date 11/19/87
Test Installation 42-in (1.07-m)
                 F-shape Bridge Railing
Installation Length . . . 100 ft (30 m)
Vehicle . . . . 1954 GMC
                 Scenicruiser Bus
Vehicle Weight
  Empty Weight . . . . . 29,840 lb (13 547 kg)
  Test Inertia . . . . . 40,560 lb (18 414 kg)
Vehicle Damage Classification
  TAD . . . . N/A
  CDC . . . . N/A
Maximum Vehicle Crush . 4.0 in (102 mm)

Impact Speed. . . . . 55.7 mi/h (89.6 km/h)
Impact Angle. . . . . 15.7 deg
Exit Speed . . . . . 42.5 mi/h (68.4 km/h)
Exit Trajctory . . . 0 deg
Vehicle Accelerations
  (Max. 0.050-sec Avg)
  Longitudinal. . . -1.5 g
  Lateral . . . . . 6.5 g
Occupant Impact Velocity
  Longitudinal. . . 7.9 ft/s (2.4 m/s)
  Lateral . . . . . 5.4 ft/s (1.6 m/s)
Occupant Ridedown Accelerations
  Longitudinal. . . -2.4 g
  Lateral . . . . . 21.7 g
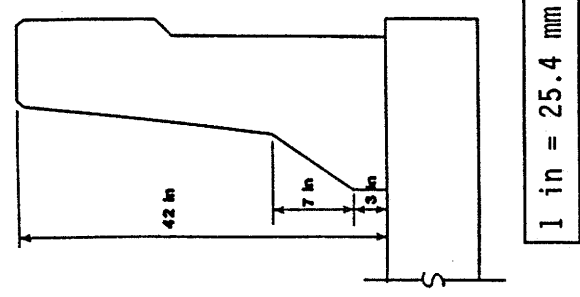
Figure 81. Summary of results for test 7069-7.

1 in = 25.4 mm

Table 34. Evaluation of crash test no. 7069-7.
{42-in (1.07 m) F-shape bridge railing [40,560 lb (18 414 kg)|55.7 mi/h (89.6 km/h)|15.7 degrees]}

CRITERIA *	TEST RESULTS	PASS/FAIL
A. Must contain vehicle	Vehicle was contained	Pass
B. Debris shall not penetrate passenger compartment	No debris penetrated passenger compartment	Pass
C. Passenger compartment must have essentially no deformation	Acceptable deformation	Pass
D. Vehicle must remain upright	Vehicle remained upright	Pass
E. Must smoothly redirect the vehicle	Vehicle was smoothly redirected	Pass
F. Effective coefficient of friction μ Assessment 0 - .25 Good .26 - .35 Fair > .35 Marginal	μ Assessment .31 Fair	Pass
G. Shall be less than Occupant Impact Velocity - ft/s (m/s) Longitudinal 30 (9.2) Lateral 25 (7.6) Occupant Ridedown Accelerations - g's Longitudinal 15 Lateral 15	Occupant Impact Velocity - ft/s (m/s) Longitudinal 7.9 (2.4) Lateral 5.4 (1.6) Occupant Ridedown Accelerations - g's Longitudinal -2.4 Lateral 21.7	N/A N/A
H. Exit angle shall be less than 12 degrees	Exit angle was 0 degrees	Pass

* A, B, C, and D are required. E, F, and H are desired. G is not applicable for this test. (See table 1)

169

Vehicle: Tractor/Trailer
Test Inertia Weight: 50,000 lb (22 700 kg)
Empty Weight: 29,900 lb (13 574 kg)
Impact Speed: 52.2 mi/h (84.0 km/h)
Impact Angle: 14.0 deg

The vehicle impacted the bridge railing (figure 82) at 35 ft (10.1 m) from the upstream end. At approximately 0.005 s after impact the right front wheel contacted the bridge railing and began to ride up the face of the bridge railing. The right front wheel left the pavement at 0.032 s, and the left front wheel left the pavement at 0.120 s. The vehicle began to redirect at 0.124 s as the rear end began to slide toward the bridge railing. At 0.260 s the right front corner of the trailer contacted the top of the bridge railing. The rear wheels of the tractor lost contact with the pavement at 0.309 s, and the tractor remained airborne until 0.594 s when the front wheels touched down. The rear trailer wheels contacted the bridge railing at about 0.785 s. The vehicle rode against the bridge railing and off the end. The brakes were applied and the vehicle subsequently came to rest approximately 300 ft (91 m) downstream from the point of impact.

The railing received only cosmetic damage (figure 83). There were tire marks on the bridge railing from just before the impact point extending a total of 72 ft (21.9 m) along the face. There was also a piece of the top of the bridge railing chipped off where the edge of the trailer impacted.

The vehicle sustained extensive damage to the right side (figure 83). Maximum crush at the right front corner at bumper height was 18.0 in (457 mm). Both outside right rear wheel rims of the tractor were bent and the tires were deflated. The front wheel assembly and suspension were damaged. The shock mounts were broken, the tie rods bent, the steering rod was bent, and the springs were loose. The right side door was dented.

The railing contained and smoothly redirected the vehicle with no lateral movement of the railing. There were no debris or detached elements. There was no intrusion into the occupant compartment although some deformation of the right door occurred. The vehicle trajectory at loss of contact indicated minimum intrusion into adjacent traffic lanes. The vehicle remained upright and stable during the entire test period.

Performance of the railing in this test is judged acceptable, as indicated in figure 84 and table 35.
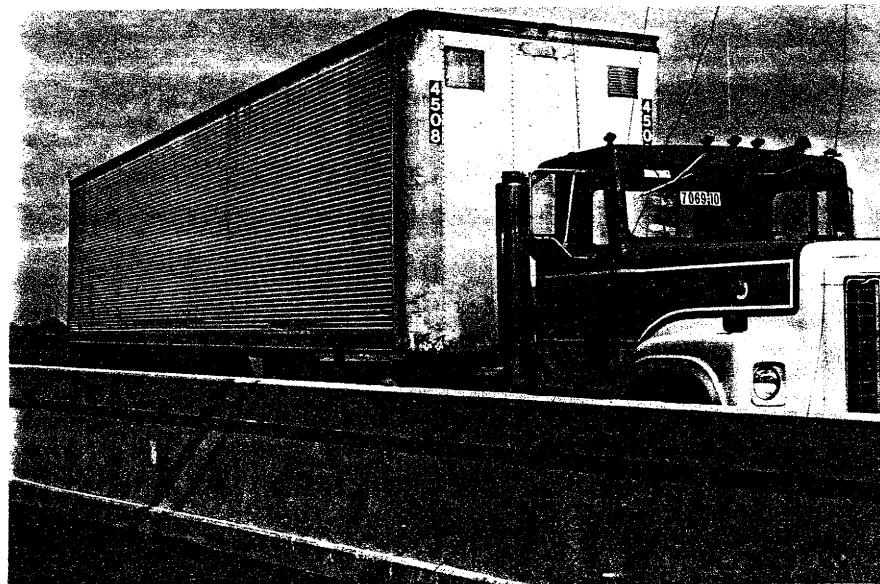
Figure 82. Vehicle and parapet before test 7069-10.

171
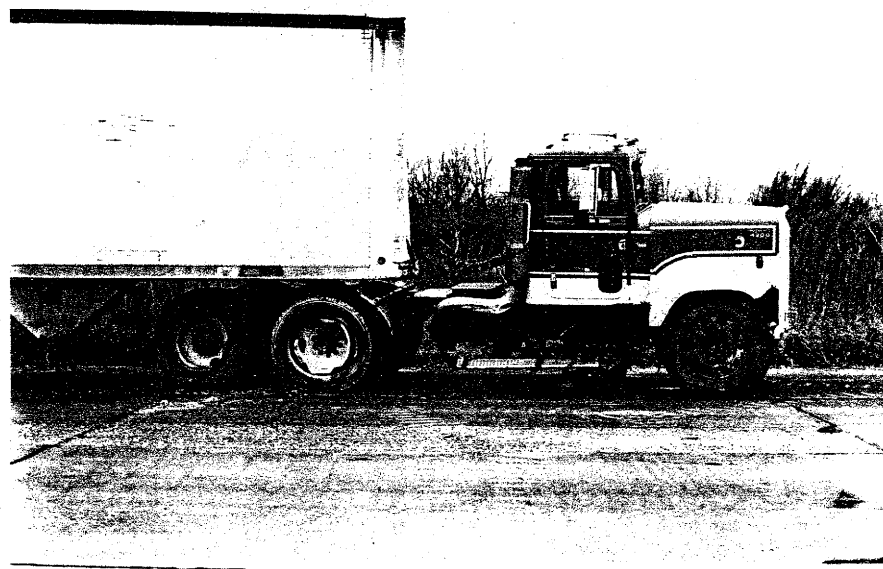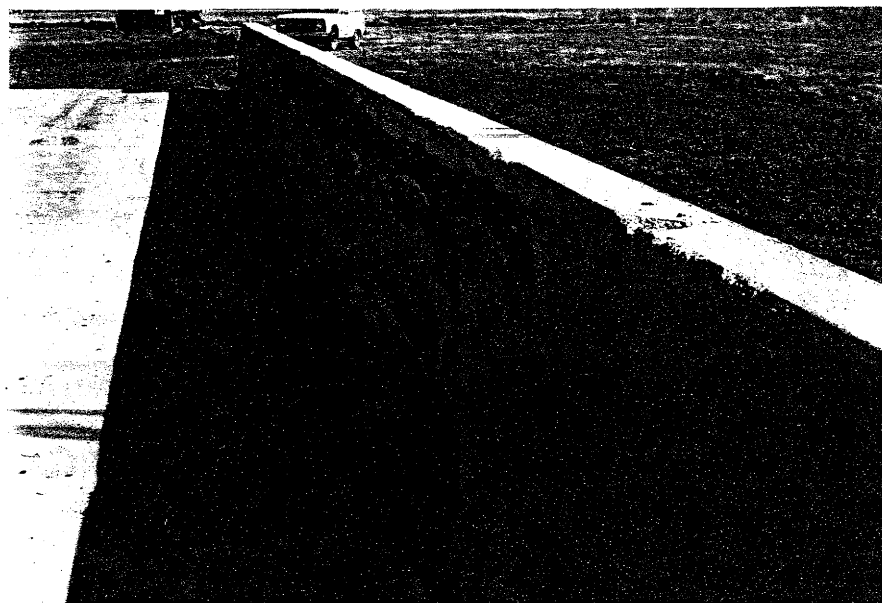
Figure 83. Vehicle and parapet after test 7069-10.

173

| | 0.000 s | 0.175 s | 0.350 s | 0.700 s |
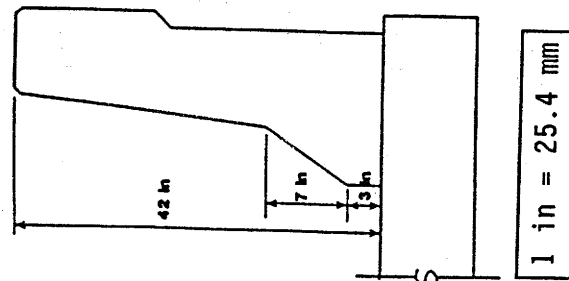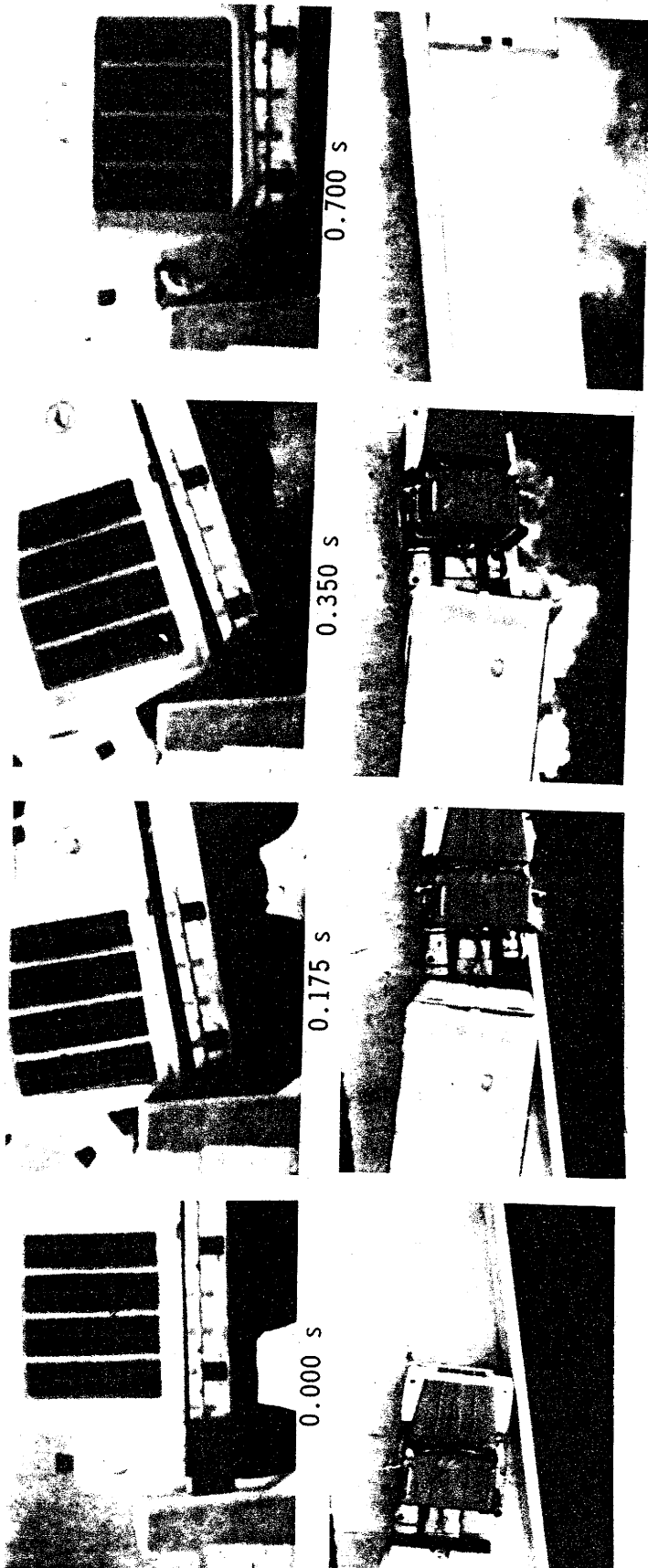
Test No. 7069-10
Date 3/3/88
Test Installation . . . 42-in (1.07-m)
                        F-shape Bridge Railing
Installation Length . . 100 ft (30 m)
Vehicle . . . . 1979 International
                        Transtar 4200 Tractor
Vehicle Weight
  Empty Weight . . . . . 29,900 lb (13 574 kg)
  Test Inertia . . . . . 50,000 lb (22 700 kg)
Maximum Vehicle Crush . 18.0 in (457 mm)

Impact Speed. . . . . 52.2 mi/h (84.0 km/h)
Impact Angle. . . . . 14.0 deg
Exit Speed. . . . . . N/A
Exit Trajectory . . . 0 deg
Vehicle Accelerations
  (Max. 0.050-sec Avg)
  Longitudinal. . . . -2.2 g
  Lateral . . . . . . 4.7 g
Occupant Impact Velocity
  Longitudinal. . . . 9.1 ft/s (2.8 m/s)
  Lateral . . . . . . 9.3 ft/s (2.8 m/s)
Occupant Ridedown Accelerations
  Longitudinal. . . . -4.7 g
  Lateral . . . . . . 3.7 g

Figure 84. Summary of results for test 7069-10.

1 in = 25.4 mm

Table 35. Evaluation of crash test no. 7069-10.
{42-in (1.07 m) F-shape bridge railing [50,000 lb (22 700 kg)|52.2 mi/h (84 km/h)|14.0 degrees]}

	CRITERIA	TEST RESULTS	PASS/FAIL*
A.	Must contain vehicle	Vehicle was contained	Pass
B.	Debris shall not penetrate passenger compartment	No debris penetrated passenger compartment	Pass
C.	Passenger compartment must have essentially no deformation	Acceptable deformation	Pass
D.	Vehicle must remain upright	Vehicle remained upright	Pass
E.	Must smoothly redirect the vehicle	Vehicle was smoothly redirected	Pass
F.	Effective coefficient of friction $\underline{\mu}$ $\underline{Assessment}$ 0 - .25 Good .26 - .35 Fair > .35 Marginal	$\underline{\mu}$ $\underline{Assessment}$ NOT AVAILABLE	N/A
G.	Shall be less than Occupant Impact Velocity - ft/s (m/s) Longitudinal Lateral 30 (9.2) 25 (7.6) Occupant Ridedown Accelerations - g's Longitudinal Lateral 15 15	Occupant Impact Velocity - ft/s (m/s) Longitudinal Lateral 9.1 (2.8) 9.3 (2.8) Occupant Ridedown Accelerations - g's Longitudinal Lateral -4.7 3.7	N/A N/A
H.	Exit angle shall be less than 12 degrees	about 0 degrees	Pass

* A, B, C, are required. D, E, F, and H are desired. G is not applicable for this test. (See table 1)

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TRANSITIONS

Two transition designs were tested, one for performance level one and one for performance level two, as shown in table 36.

The Oregon thrie-beam transition was designed to transition between a standard W-beam guardrail and the Oregon side-mounted thrie-beam bridge railing. It was tested to performance level one requirements and showed acceptable performance.

The 32-in (813-mm) thrie-beam transition was designed to transition between a standard W-beam guardrail and a performance level two bridge railing. It was tested to and meets requirements of performance level two. For testing, the transition was mounted on the end of the 32-in (813-mm) concrete parapet, but it should be useable on other performance level two bridge railings if suitable attachment to the bridge railing can be made.

Table 36. Summary of tests performed on transitions.

RAILING DESIGN	TEST NO.	TEST DATE	ACTUAL CONDITIONS	DESIGN CONDITIONS	COMMENTS
OREGON TRANSITION	7069-27	6/16/92	1,970 lb|51.6 mi/h|19.9 deg (894 kg|83.0 km/h|19.9 deg)	1,800 lb|50 mi/h|20 deg (817 kg|80.5 km/h|20 deg)	Acceptable
	7069-28	6/16/92	5,565 lb|47.7 mi/h|19.0 deg (2 527 kg|76.7 km/h|19.0 deg)	5,400 lb|45 mi/h|20 deg (2 452 kg|72.4 km/h|20 deg)	Acceptable
32-in (813-mm) THRIE-BEAM TRANSITION	7069-19	10/2/90	1,970 lb|60.5 mi/h|19.9 deg (894 kg|97.3 km/h|19.9 deg)	1,800 lb|60 mi/h|20 deg (817 kg|96.5 km/h|20 deg)	Marginal
	7069-20	10/19/90	5,570 lb|62.7 mi/h|19.0 deg (2 529 kg|100.9 km/h|19.0 deg)	5,400 lb|60 mi/h|20 deg (2 452 kg|96.5 km/h|20 deg)	Unacceptable
	7069-21	3/17/92	5,565 lb|61.4 mi/h|18.3 deg (2 527 kg|98.8 km/h|18.3 deg)	5,400 lb|60 mi/h|20 deg (2 452 kg|96.5 km/h|20 deg)	Acceptable
	7069-29	6/5/92	18,000 lb|51.6 mi/h|14.6 deg (8 172 kg|83.0 km/h|14.6 deg)	18,000 lb|50 mi/h|15 deg (8 172 kg|80.5 km/h|15 deg)	Acceptable

Oregon Thrie-Beam Transition

Test Number 7069-27

Vehicle:	1983 Honda Civic
Test Inertia Weight:	1,800 lb (817 kg)
Gross Static Weight:	1,970 lb (894 kg)
Impact Speed:	51.6 mi/h (83.0 km/h)
Impact Angle:	19.9 deg

At 0.017 s after impact the bumper of the vehicle began to shift to the right, and at 0.029 s the front of the vehicle began to deform to the right. The vehicle began to redirect at 0.050 s after impact, and at the same time the vehicle contacted post 1. By 0.133 s the vehicle was traveling parallel to the transition at a speed of 44.9 mi/h (72.2 km/h), and at 0.150 s the rear of the vehicle impacted the transition at the post 2 location. At 0.176 s the dummy's shoulder shattered the window glass on the driver side. The vehicle lost contact with the transition at 0.245 s traveling at 44.3 mi/h (71.3 km/h) and 9.1 degrees. The vehicle was in contact with the transition for 9.0 ft (2.7 m). The brakes were applied at 1.4 s after impact and subsequently stopped (32 m) from the point of impact, resting against another barrier.

The transition received minimal damage (figure 85). Maximum lateral permanent deformation was 0.5 in (13 mm).

The vehicle sustained damage to the left side as shown in figure 8. Maximum crush at the left front corner at bumper height was 8.0 in (203 mm), and the driver door was deformed outward approximately 8.0 in (203 mm). The driver side window was broken out and the door was jammed. Also, damage was done to the front bumper, hood, grill, left front quarter panel, left rear quarter panel, and left front tire and rim.

The transition contained the vehicle with minimal lateral movement of the transition. There was no intrusion of transition components into the occupant compartment. The vehicle remained upright and relatively stable during the collision. The transition redirected the vehicle and the effective coefficient of friction was considered good. Velocity change of the vehicle during the collision was 7.3 mi/h (11.7 km/h). The occupant impact velocities and the occupant ridedown accelerations were within the limits. The vehicle trajectory at loss of contact indicated minimum intrusion into adjacent traffic lanes.

Performance of the transition in this test is judged acceptable, as indicated in figure 86 and table 37.
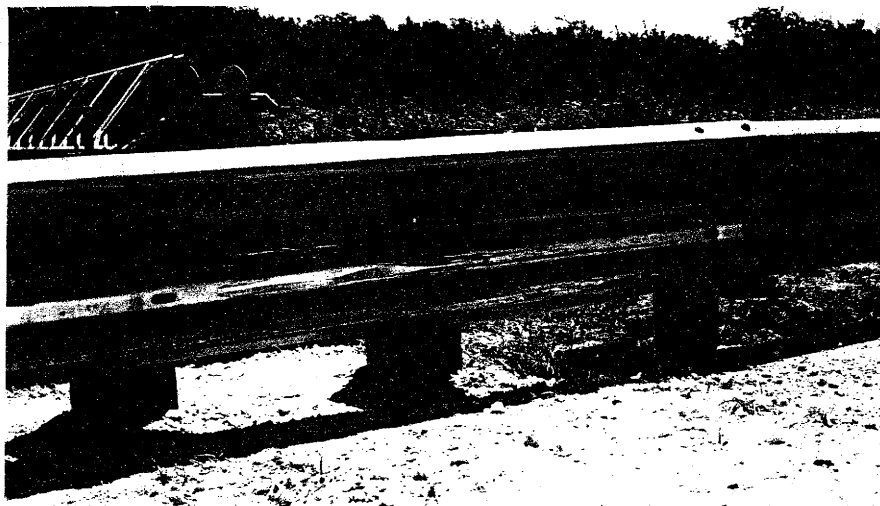
Figure 85. Vehicle and transition for test 7069-27.

0.000 s   0.071 s   0.143 s   0.250 s
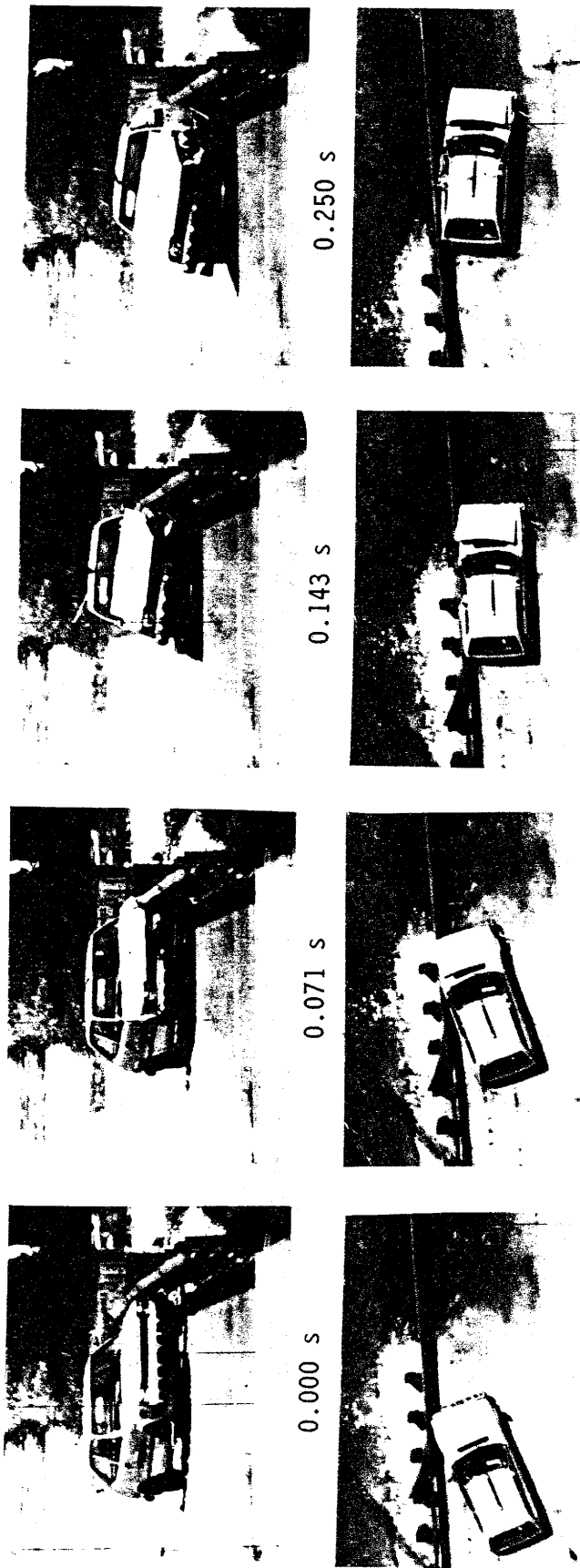
Test No. 7069-27
Date 06/16/92
Test Installation . . . . Oregon Thrie-beam
                          Transition
Installation Length . . . 85 ft (26 m)

Test Vehicle . . . . 1983 Honda Civic
Vehicle Weight
    Test Inertia . . . . . 1,800 lb (817 kg)
    Gross Static . . . . . 1,970 lb (894 kg)
Vehicle Damage Classification
    TAD . . . . 11LFQ4 & 11LD1
    CDC . . . . 11FLEK2 & 11LDEW3
Maximum Vehicle Crush . . 8.0 in (203 mm)

Impact Speed. . . . . . . 51.6 mi/h (83.0 km/h)
Impact Angle. . . . . . . 19.9 deg
Speed at Parallel . . . . 44.9 mi/h (72.2 km/h)
Exit Speed . . . . 44.3 mi/h (71.3 km/h)
Exit Trajectory . . . . . 9.1 deg
Vehicle Accelerations
    (Max. 0.050-sec Avg) at true c.g.
    Longitudinal. . . . . -5.3 g
    Lateral . . . . -10.9 g
Occupant Impact Velocity at true c.g.
    Longitudinal. . . . . 13.1 ft/s (4.0 m/s)
    Lateral . . . . 23.7 ft/s (7.2 m/s)
Occupant Ridedown Accelerations
    Longitudinal . . . . 1.0 g
    Lateral . . . . -9.6 g
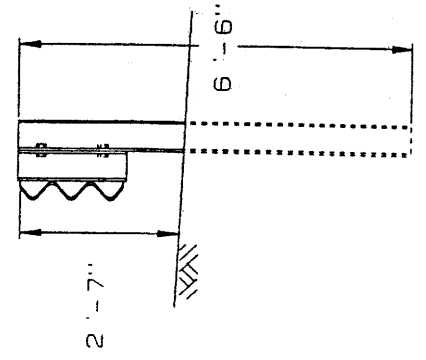
| 1 in = 25.4 mm |
| 1 ft = 0.305 m |

Figure 86. Summary of results for test 7069-27.

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Table 37. Evaluation of crash test no. 7069-27.
{Oregon transition [1,800 lb (817 kg)|51.6 mi/h (83.0 km/h)|19.9 degrees}

	CRITERIA	TEST RESULTS	PASS/FAIL*
A.	Must contain vehicle	Vehicle was contained	Pass
B.	Debris shall not penetrate passenger compartment	No debris penetrated passenger compartment	Pass
C.	Passenger compartment must have essentially no deformation	No deformation	Pass
D.	Vehicle must remain upright	Vehicle did remain upright	Pass
E.	Must smoothly redirect the vehicle	Vehicle was smoothly redirected	Pass
F.	Effective coefficient of friction $\underline{\mu}$ $\underline{Assessment}$ 0 - .25 Good .26 - .35 Fair > .35 Marginal	$\underline{\mu}$ $\underline{Assessment}$ .21 Good	Pass
G.	Shall be less than $\underline{Occupant\ Impact\ Velocity - ft/s\ (m/s)}$ Longitudinal Lateral 30 (9.2) 25 (7.6) $\underline{Occupant\ Ridedown\ Accelerations - g's}$ Longitudinal Lateral 15 15	$\underline{Occupant\ Impact\ Velocity - ft/s\ (m/s)}$ Longitudinal Lateral 13.1 (4.0) 23.7 (7.2) $\underline{Occupant\ Ridedown\ Accelerations - g's}$ Longitudinal Lateral 1.0 -9.6	Pass
H.	Exit angle shall be less than 12 degrees	Exit angle was 9.1 degrees	Pass

* A, B, C, D and G are required. E, F, and H are desired. (See table 1)

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Vehicle: 1985 Chevrolet Pickup
Test Inertia Weight: 5,400 lb (2 452 kg)
Gross Static Weight: 5,565 lb (2 527 kg)
Impact Speed: 47.7 mi/h (76.7 km/h)
Impact Angle: 19.0 deg

The vehicle began to redirect at 0.062 s after impact, and at 0.129 the right front tire left the roadway. By 0.192 s the vehicle was traveling parallel to the transition at a speed of 45.5 mi/h (73.2 km/h), and at 0.205 s the rear of the vehicle impacted the transition. The transition reached a maximum deflection of 0.9 ft at 0.271 s after impact, and the right rear wheel lost contact with the roadway at 0.298 s. The vehicle lost contact with the transition at 0.370 s traveling at 42.8 mi/h (68.9 km/h) and 8.9 degrees. The vehicle was in contact with the transition for 14.0 ft (4.3 m). The right side of the vehicle regained contact with the roadway at 0.576 s. The brakes were applied at 1.5 s after impact and subsequently came to rest 285 ft (87 m) down from and 98 ft (30 m) in front of the point of impact.

The transition received minimal damage (figure 87). Maximum lateral permanent deformation was 3.5 in (89 mm).

The vehicle sustained damage to the left side (figure 87). Maximum crush at the left front corner at bumper height was 8.0 in (203 mm), and the driver door was deformed outward approximately 1.0 in (25 mm). The frame was bent and the cab was deformed. The driver side window was broken out and the door was jammed. Also, damage was done to the front bumper, hood, grill, left front quarter panel, left rear quarter panel, rear bumper, and left front tire and rim.

The transition contained the vehicle with minimal lateral movement of the transition. There was no intrusion of railing components into the occupant compartment. The vehicle remained upright and relatively stable during the collision. The transition redirected the vehicle and the effective coefficient of friction was considered good. Velocity change of the vehicle during the collision was 4.9 mi/h (7.9 km/h). The occupant impact velocities and the occupant ridedown accelerations were within the limits. The vehicle trajectory at loss of contact indicated minimum intrusion into adjacent traffic lanes.

Performance of the transition in this test is judged acceptable, as indicated in figure 88 and table 38.

181
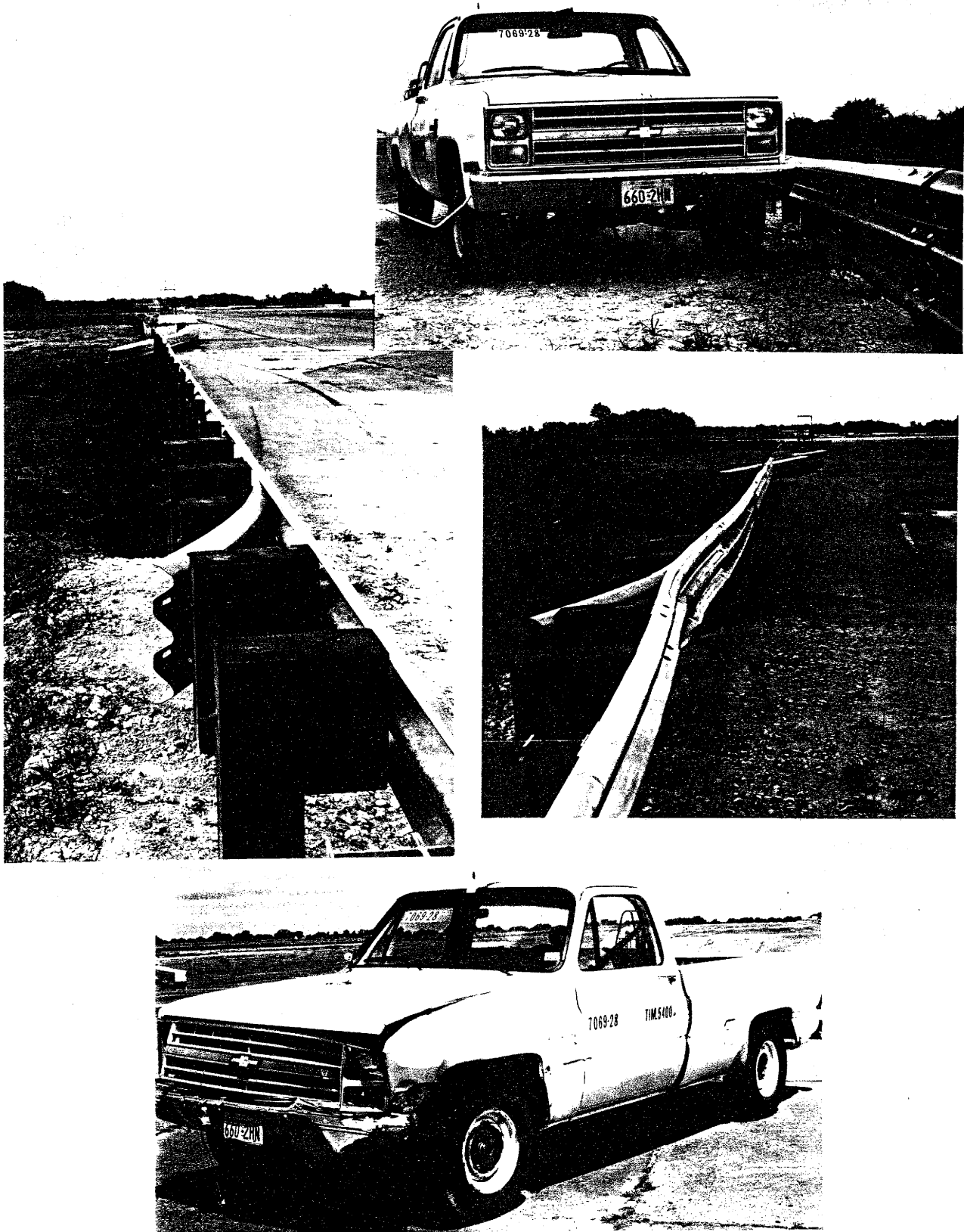
Figure 87. Vehicle and transition for test 7069-28.

182
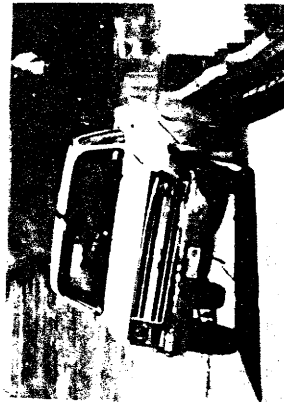
0.000 s	0.099 s	0.200 s	0.402 s
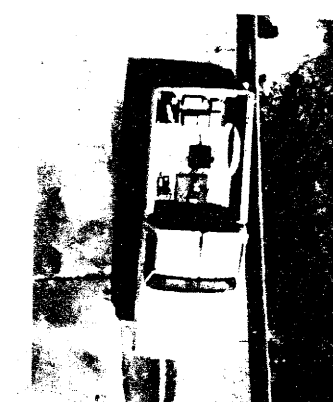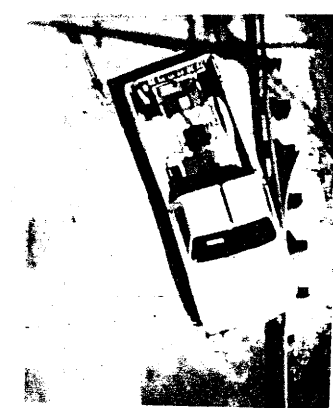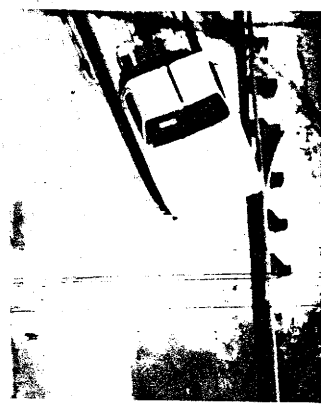
Test No. 7069-28
Date 06/18/92

Test Installation . . . . Oregon Thrie-beam
Transition

Installation Length . . 85 ft (26 m)

Test Vehicle . . . . 1985 Chevrolet
Vehicle Weight . . . . . . C-20 Pickup
Test Inertia . . . . 5,400 lb (2 452 kg)
Gross Static . . . . 5,565 lb (2 527 kg)
Vehicle Damage Classification
TAD . . . . 11LFQ2 & 11LD2
CDC . . . . 11FLEK2 & 11LDEW3
Maximum Vehicle Crush . 8.0 in (203 mm)
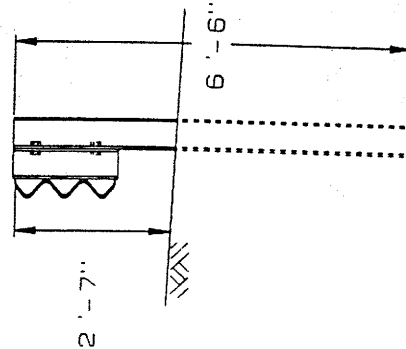
Impact Speed. . . . . . . 47.7 mi/h (76.7 km/h)
Impact Angle. . . . . . . 19.0 deg
Speed at Parallel . . . . 45.5 mi/h (73.2 km/h)
Exit Speed . . . . 42.8 mi/h (68.9 km/h)
Exit Trajectory . . . . . 8.9 deg
Vehicle Accelerations
(Max. 0.050-sec Avg) at true c.g.
Longitudinal. . . . . . -2.2 g
Lateral . . . . -7.3 g
Occupant Impact Velocity at true c.g.
Longitudinal. . . . . . 7.2 ft/s (2.2 m/s)
Lateral . . . . 16.2 ft/s (4.9 m/s)
Occupant Ridedown Accelerations
Longitudinal . . . . . 1.1 g
Lateral . . . . -9.6 g

1 in = 25.4 mm
1 ft = 0.305 m

Figure 88. Summary of results for test 7069-28.

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Table 38. Evaluation of crash test no. 7069-28.
{Oregon transition [5,400 lb (2 452 kg)|47.7 mi/h(76.7 km/h)|19.0 degrees]}

	CRITERIA	TEST RESULTS	PASS/FAIL*
A.	Must contain vehicle	Vehicle was contained	Pass
B.	Debris shall not penetrate passenger compartment	No debris penetrated passenger compartment	Pass
C.	Passenger compartment must have essentially no deformation	No deformation	Pass
D.	Vehicle must remain upright	Vehicle did remain upright	Pass
E.	Must smoothly redirect the vehicle	Vehicle was smoothly redirected	Pass
F.	Effective coefficient of friction μ — Assessment 0 - .25 — Good .26 - .35 — Fair > .35 — Marginal	μ — Assessment .02 — Good	Pass
G.	Shall be less than Occupant Impact Velocity - ft/s (m/s) Longitudinal — Lateral 30 (9.2) — 25 (7.6) Occupant Ridedown Accelerations - g's Longitudinal — Lateral 15 — 15	Occupant Impact Velocity - ft/s (m/s) Longitudinal — Lateral 7.2 (2.2) — 16.2 (4.9) Occupant Ridedown Accelerations - g's Longitudinal — Lateral 1.1 — -9.6	Pass
H.	Exit angle shall be less than 12 degrees	Exit angle was 8.9 degrees	Pass

* A, B, C, and D are required. E, F, G, and H are desired. (See table 1)

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32-in (813-mm) Thrie-Beam Transition

Test Number 7069-19

Vehicle:	1983 Honda Civic
Test Inertia Weight:	1,800 lb (817 kg)
Gross Static Weight:	1,970 lb (894 kg)
Impact Speed:	60.5 mi/h (97.3 km/h)
Impact Angle:	19.9 deg

The vehicle impacted the transition approximately 0.4 ft (0.1 m) down from post 2. The vehicle began to redirect at 0.030 s after impact. At approximately 0.050 s the vehicle began to deform at the A-pillar, and at 0.088 s the door glass shattered. By 0.137 s the vehicle was traveling parallel to the transition at a speed of 51.0 mi/h (82.1 km/h), and at the same time the rear of the vehicle impacted the transition. The vehicle lost contact with the transition at 0.219 s traveling at 47.7 mi/h (76.7 km/h) and 6.9 degrees. The vehicle was in contact with the transition for 8.5 ft (2.6 m). The brakes were applied, the vehicle yawed clockwise, and it subsequently came to rest 240 ft (73 m) down and 100 ft (30 m) in front of the point of impact.

The transition received minor damage, most of which was cosmetic in nature (figure 89). Maximum lateral deformation was 0.5 in (13 mm) at the post 2.

The vehicle sustained damage to the left side (figure 89). Maximum crush at the left front corner at bumper height was 11.0 in (279 mm). The strut and constant velocity joint on the left side were damaged and the roof was bent. The left front wheel was canted inward at the bottom and pushed back into the fender well. The left side window was broken out by the dummy's head. Also, damage was done to the front bumper, hood, grill, radiator and fan, left front quarter panel, left door, left rear quarter panel, and left rear tire and rim.

The transition contained the vehicle with minimal lateral movement of the transition. There was no intrusion into the occupant compartment with minimal (but acceptable) deformation of the passenger compartment. The vehicle remained upright and relatively stable during the collision. The transition smoothly redirected the vehicle and the effective coefficient of friction was considered fair. The lateral occupant impact velocity of 25.9 ft/s (7.9 m/s) in this test did not meet with the AASHTO specifications. The longitudinal occupant impact velocity and the occupant ridedown accelerations were within the limits. The vehicle trajectory at loss of contact indicated minimum intrusion into adjacent traffic lanes.

Performance of the transition in this test is judged acceptable, as indicated in figure 90 and table 39.

185
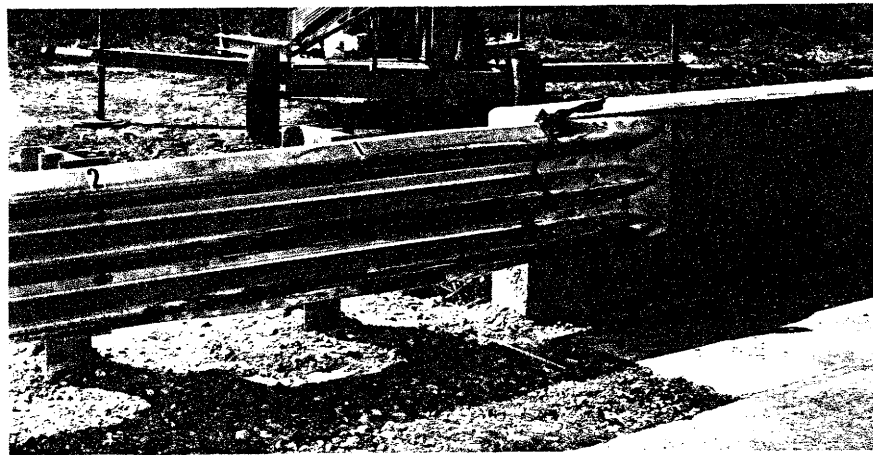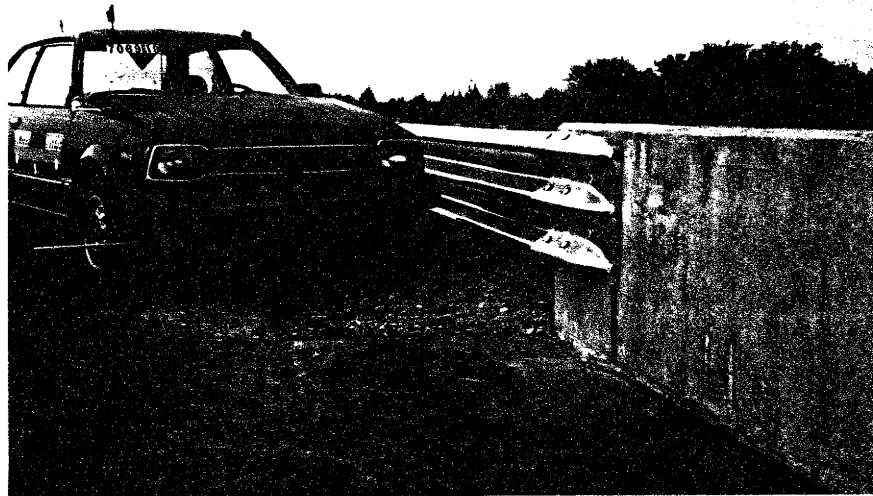
Figure 89. Vehicle and transition for test 7069-19.

Test No.	7069-19
Date	10/02/90
Test Installation	32-in (813-mm) Thrie-Beam Transition
Installation Length . . .	85 ft (26 m)
Test Vehicle	1983 Honda Civic
Vehicle Weight	
Test Inertia	1,800 lb (817 kg)
Gross Static	1,970 lb (894 kg)
Vehicle Damage Classification	
TAD	11FL4 & 11LD6
CDC	11FLEK2 & 11LDEW3
Maximum Vehicle Crush .	11.0 in (279 mm)

Impact Speed. . . .	60.5 mi/h (97.3 km/h)
Impact Angle. . . .	19.9 deg
Speed at Parallel .	51.0 mi/h (82.1 km/h)
Exit Speed	47.7 mi/h (76.7 km/h)
Exit Trajectory . .	6.9 deg
Vehicle Accelerations	
(Max. 0.050-sec Avg) at true c.g.	
Longitudinal. . . .	-8.5 g
Lateral	-14.3 g
Occupant Impact Velocity (at true c.g.)	
Longitudinal. . . .	19.3 ft/s (5.9 m/s)
Lateral	25.9 ft/s (7.9 m/s)
Occupant Ridedown Accelerations	
Longitudinal. . . .	-2.3 g
Lateral	-12.5 g
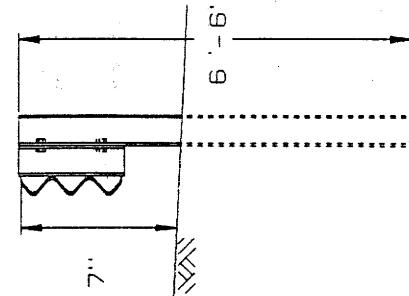
Figure 90. Summary of results for test 7069-19.

1 in = 25.4 mm
1 ft = 0.305 m

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Table 39. Evaluation of crash test no. 7069-19.
{32-in (813-mm) thrie-beam transition [1,800 lb (817 kg)|60.5 mi/h (97.3 km/h)|19.9 degrees]}

	CRITERIA	TEST RESULTS	PASS/FAIL*
A.	Must contain vehicle	Vehicle was contained	Pass
B.	Debris shall not penetrate passenger compartment	No debris penetrated passenger compartment	Pass
C.	Passenger compartment must have essentially no deformation	Acceptable deformation	Pass
D.	Vehicle must remain upright	Vehicle did remain upright	Pass
E.	Must smoothly redirect the vehicle	Vehicle was smoothly redirected	Pass
F.	Effective coefficient of friction _μ_ Assessment 0 - .25 Good .26 - .35 Fair > .35 Marginal	_μ_ Assessment .29 Fair	Pass
G.	Shall be less than Occupant Impact Velocity - ft/s (m/s) Longitudinal Lateral 30 (9.2) 25 (7.6) Occupant Ridedown Accelerations - g's Longitudinal Lateral 15 15	Occupant Impact Velocity - ft/s (m/s) Longitudinal Lateral 19.3 (5.9) 25.9 (7.9) Occupant Ridedown Accelerations - g's Longitudinal Lateral -2.3 -11.5	Fail Pass
H.	Exit angle shall be less than 12 degrees	Exit angle was 6.9 degrees	Pass

* A, B, C, D and G are required. E, F, and H are desired. (See table 1)

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Vehicle:	1981 Chevrolet Pickup
Test Inertia;	5,400 lb (2 452 kg)
Gross Static Weight:	5,570 lb (2 529 kg)
Impact Speed:	62.7 mi/h (100.9 km/h)
Impact Angle:	19.0 deg

The vehicle impacted the transition approximately 7 ft (2.1 m) upstream from the end of the concrete parapet (figure 91). The vehicle began to redirect at 0.022 s after impact. At approximately 0.103 s the left door began to come open, and at 0.135 s the front edge of the door began to peel away from the hinges. By 0.204 s the vehicle was traveling parallel to the transition at a speed of 46.8 mi/h (75.3 km/h), and at the same time the rear of the vehicle impacted the transition. Maximum lateral deflection of 0.9 ft (0.3 m) occurred at 0.231 s. The vehicle lost contact with the transition at 0.308 s traveling at 41.9 mi/h (67.4 km/h) and 9.0 degrees. The vehicle was in contact with the transition for 8.5 ft (2.6 m). The brakes were applied, the vehicle yawed counter-clockwise, and it subsequently came to rest 135 ft (41 m) down from the point of impact.

The transition received moderate damage (figure 92). Maximum lateral deformation was 6.5 in (165 mm).

The vehicle sustained damage to the left side (figure 92). Maximum crush at the left front corner at bumper height was 22.0 in (559 mm). The sway bar and upper and lower control arm on the left side were damaged and the roof was bent. The left front wheel was canted inward at the bottom and pushed back into the fender well. The left side window was broken out. The door was separated from the vehicle and remained affixed to the transition at the terminal connector. Also, damage was done to the front bumper, hood, grill, radiator and fan, left front quarter panel, left rear quarter panel, and left rear tire and rim.

The transition contained the vehicle with minimal lateral movement of the transition. There was no intrusion of railing components into the occupant compartment; however, the door was detached from the vehicle and remained lodged on the railing. The vehicle remained upright and relatively stable during the collision. The transition redirected the vehicle but the effective coefficient of friction was quite high. Velocity change of the vehicle during the collision was 20.8 mi/h. The occupant impact velocities and the occupant ridedown accelerations were within the limits. The vehicle trajectory at loss of contact indicated minimum intrusion into adjacent traffic lanes.

Performance of the transition in this test is judged unacceptable, as indicated in figure 93 and table 40.
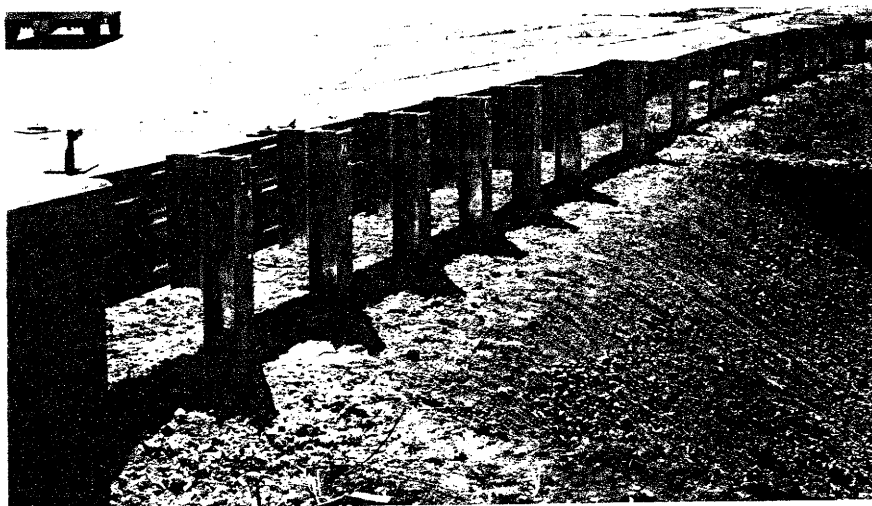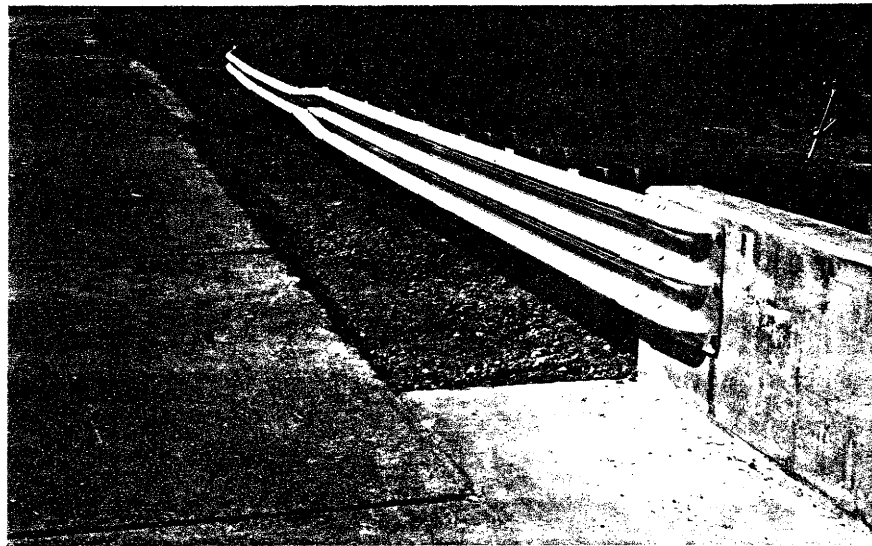
Figure 91. Vehicle and transition before test 7069-20.

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Figure 92. Vehicle and transition after test 7069-20.

191

0.000 s

0.089 s

0.177 s

0.266 s

2'-7"

6'-6"
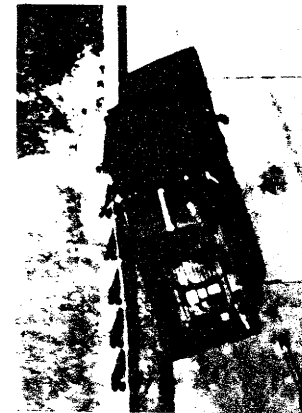
Test No. 7069-20
Date 10/19/90

Test Installation . . . 32-in (813-mm)
                        Thrie-Beam Transition

Installation Length . . 85 ft (26 m)

Test Vehicle . . . . . . 1981 Chevrolet
                        C-20 Pickup

Vehicle Weight
    Test Inertia . . . . . . 5,400 lb (2 452 kg)
    Gross Static . . . . . 5,570 lb (2 529 kg)
Vehicle Damage Classification
    TAD . . . . 11FL5 & 11LD7
    CDC . . . . 11FLEK3 & 11LDEW3
Maximum Vehicle Crush . 22.0 in (559 mm)

Impact Speed. . . . . . 62.7 mi/h (100.9 km/h)
Impact Angle. . . . . . 19.0 deg
Speed at Parallel . . . 46.8 mi/h (75.3 km/h)
Exit Speed . . . . . . 41.9 mi/h (67.4 km/h)
Exit Trajectory . . . . 9.0 deg
Vehicle Accelerations
    (Max. 0.050-sec Avg) at true c.g.
    Longitudinal. . . . -6.4 g
    Lateral . . . . . . -7.7 g
Occupant Impact Velocity
    Longitudinal. . . . 19.3 ft/s (5.9 m/s)
    Lateral . . . . . . 17.3 ft/s (5.3 m/s)
Occupant Ridedown Accelerations
    Longitudinal. . . . -5.4 g
    Lateral . . . . . . -13.0 g
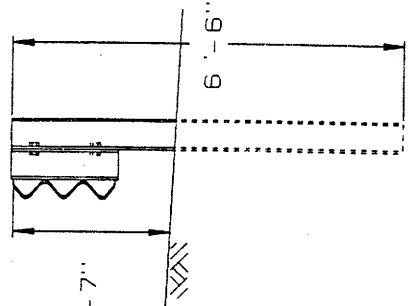
1 in = 25.4 mm
1 ft = 0.305 m

Figure 93.   Summary of results for test 7069-20.

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Table 40. Evaluation of crash test no. 7069-20.
{32-in (813-mm) thrie-beam transition [5,400 lb (2 452 kg)|62.7 mi/h (100.9 km/h)|19.0 degrees]}

	CRITERIA	TEST RESULTS	PASS/FAIL*
A.	Must contain vehicle	Vehicle was contained	Pass
B.	Debris shall not penetrate passenger compartment	No debris penetrated passenger compartment	Pass
C.	Passenger compartment must have essentially no deformation	Moderate deformation Door detached	Fail
D.	Vehicle must remain upright	Vehicle did remain upright	Pass
E.	Must smoothly redirect the vehicle	Vehicle was smoothly redirected	Pass
F.	Effective coefficient of friction μ — Assessment 0 - .25 — Good .26 - .35 — Fair > .35 — Marginal	μ — Assessment .61 — Marginal	Fail
G.	Shall be less than Occupant Impact Velocity - ft/s (m/s) Longitudinal 30 (9.2) — Lateral 25 (7.6)	Occupant Impact Velocity - ft/s (m/s) Longitudinal 19.3 (5.9) — Lateral 17.3 (5.3)	Pass
	Occupant Ridedown Accelerations - g's Longitudinal 15 — Lateral 15	Occupant Ridedown Accelerations - g's Longitudinal -5.4 — Lateral -13.0	Pass
H.	Exit angle shall be less than 12 degrees	Exit angle was 6.9 degrees	Pass

* A, B, C, and D are required. E, F, G, and H are desired. (See table 1)

Vehicle: 1984 Chevrolet Pickup
Test Inertia Weight: 5,400 lb (2 452 kg)
Gross Static Weight: 5,565 lb (2 527 kg)
Impact Speed: 61.4 mi/h (98.8 km/h)
Impact Angle: 18.3 deg

[NOTE: For tests 7069-21 and 29, the modified terminal connector was used.]

The vehicle impacted the transition 25 in (635 mm) upstream of post 2 (figure 94). The vehicle began to redirect at 0.026 s after impact, and at 0.042 s the vehicle contacted post 1. Maximum lateral deflection of 0.8 ft (0.3 m) occurred at 0.060 s. At approximately 0.070 s the vehicle impacted the end of the concrete parapet. The left front wheel snagged on the end of the parapet at 0.099 s causing a severe steering input to the vehicle and the passenger side of the vehicle became airborne. At approximately 0.110 s the windshield shattered, and at 0.140 s the door glass on the driver's side was broken by the dummy's head. By 0.178 s the vehicle was traveling parallel to the transition at a speed of 50.3 mi/h (80.9 km/h), and at 0.188 s the rear of the vehicle impacted the transition. At 0.210 s the dummy's head was at its maximum distance outside the vehicle (approximately 16 in (406 mm). The tailgate of the vehicle came loose at 0.267 s and, as the vehicle continued forward, the tailgate came off and traveled with the vehicle. The vehicle lost contact with the transition at 0.314 s traveling at 50.0 mi/h (80.5 km/h) and 8.2 degrees. The vehicle was in contact with the transition for 14.0 ft (4.2 m). The dummy's head impacted against the outside of the door of the vehicle as it was re-entering the vehicle at 0.440 s. The brakes were applied as the vehicle left the installation and subsequently came to rest 195 ft (41 m) from the point of impact.

The transition received moderate damage (figure 95). Maximum lateral permanent deformation was 5.0 in (127 mm).

The vehicle sustained damage to the left side (figure 95). Maximum crush at the left front corner at bumper height was 15.0 in (381 mm) and the right front corner was deformed outward approximately 4.75 in (121 mm). The sway bar and A-arms on the left side and gas tank were damaged, and the drive shaft, frame, and roof were bent. The floor pan was pushed into the occupant compartment approximately 5 to 7 in (130 to 180 mm) and the dash moved inward approximately 3 in (80 mm). The left front wheel was canted inward at the bottom and pushed back into the fender well reducing the wheelbase on the driver side by 14.0 in (356 mm). The driver side window was broken out and the door was jammed. Also, damage was done to the front bumper, hood, grill, radiator and fan, left front quarter panel, left rear quarter panel, and left rear tire and rim. The tailgate came off the vehicle during the test.

The transition contained the vehicle with minimal lateral movement of the transition. There was no intrusion of railing components into the occupant compartment; however, the floor pan was deformed into the vehicle approximately 5 to 7 in (130 to 180 mm) and the instrument panel was pushed inward approximately 3 in (80 mm). The vehicle remained
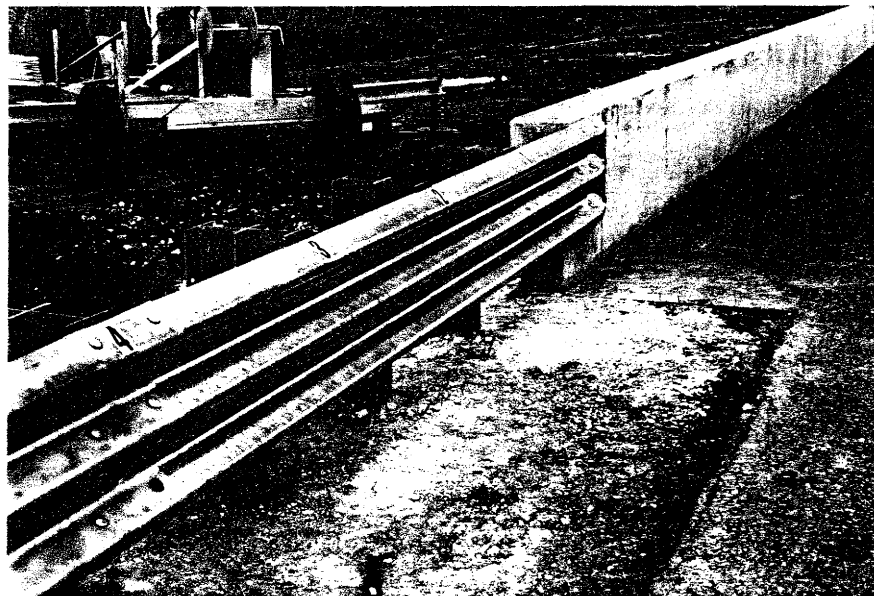
Figure 94. Vehicle and transition before test 7069-21.
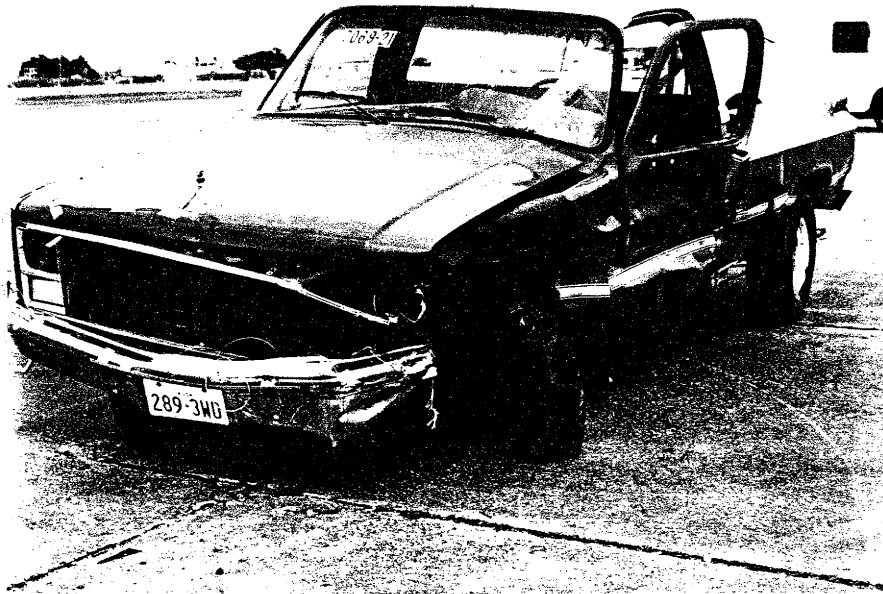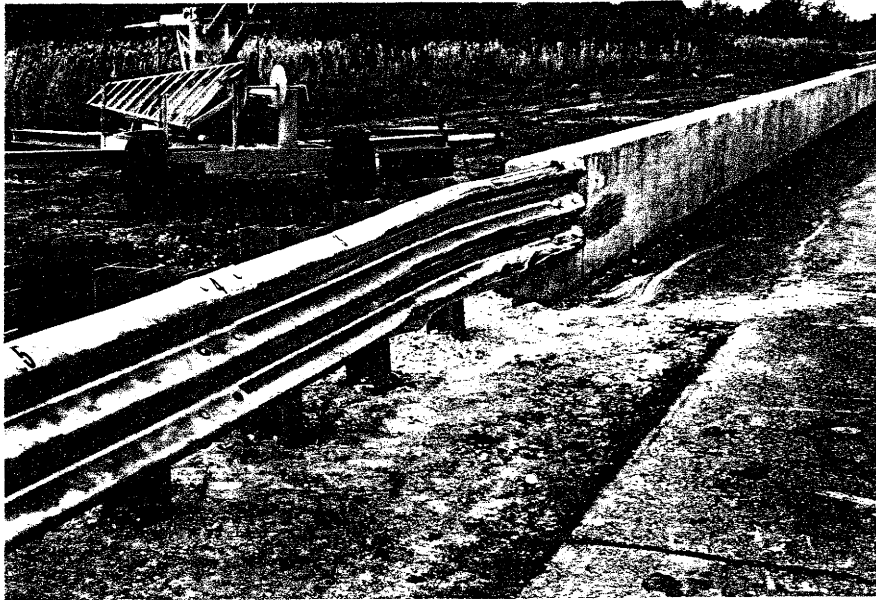
Figure 95. Vehicle and transition after test 7069-21.

upright and relatively stable during the collision. The transition redirected the vehicle but the effective coefficient of friction was quite high. Velocity change of the vehicle during the collision was 11.1 mi/h (17.9 km/h). The occupant impact velocities and the occupant ridedown accelerations were within the limits. The vehicle trajectory at loss of contact indicated minimum intrusion into adjacent traffic lanes.

Performance of the transition in this test is judged marginally acceptable, as indicated in figure 96 and table 41.

| | 0.000 s | 0.078 s | 0.157 s | 0.314 s |
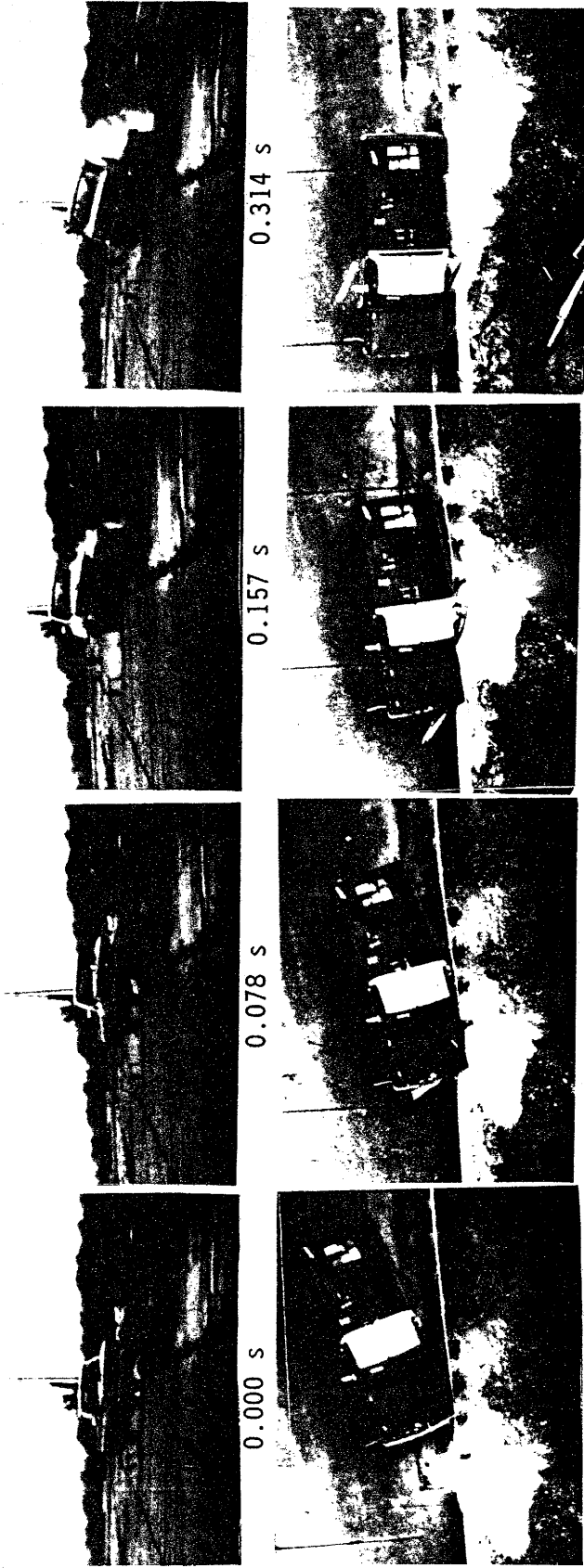
Test No. 7069-21
Date 03/17/92

Test Installation . . . 32-in (813-mm)
                        Thrie-Beam Transition
Installation Length . . 85 ft (26 m)

Test Vehicle . . . . . 1984 Chevrolet
Vehicle Weight . . . . Custom Pickup
  Test Inertia . . . . 5,400 lb (2 452 kg)
  Gross Static . . . . 5,565 lb (2 527 kg)
Vehicle Damage Classification
  TAD . . . . 11FL5 & 11LD6
  CDC . . . . 11FLEK3 & 11LDEW4
Maximum Vehicle Crush . 15.0 in (381 mm)

Impact Speed. . . . . . 61.4 mi/h (98.8 km/h)
Impact Angle. . . . . . 18.3 deg
Speed at Parallel . . . 50.3 mi/h (80.9 km/h)
Exit Speed . . . . . . 50.0 mi/h (80.5 km/h)
Exit Trajectory . . . . 8.2 deg
Vehicle Accelerations
  (Max. 0.050-sec Avg) at true c.g.
  Longitudinal. . . . . -6.9 g
  Lateral . . . . . . -10.3 g
Occupant Impact Velocity at true c.g.
  Longitudinal. . . . 19.3 ft/s (5.9 m/s)
  Lateral . . . . . 24.8 ft/s (7.6 m/s)
Occupant Ridedown Accelerations
  Longitudinal. . . . -3.7 g
  Lateral . . . . . 12.5 g
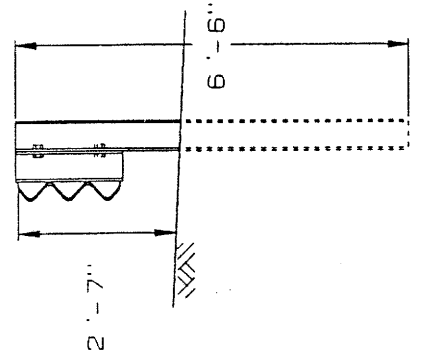
1 in = 25.4 mm
1 ft = 0.305 m

Figure 96. Summary of results for test 7069-21.

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Table 41. Evaluation of crash test no. 7069-21.
{32-in (813-mm) thrie-beam transition [5,400 lb (2 452 kg)|61.4 mi/h (98.8 km/h)|18.3 degrees]}

	CRITERIA	TEST RESULTS	PASS/FAIL*
A.	Must contain vehicle	Vehicle was contained	Pass
B.	Debris shall not penetrate passenger compartment	No debris penetrated passenger compartment	Pass
C.	Passenger compartment must have essentially no deformation	Moderate deformation (approx. 5-7 in at floorpan)	Fail
D.	Vehicle must remain upright	Vehicle did remain upright	Pass
E.	Must smoothly redirect the vehicle	Vehicle was smoothly redirected	Pass
F.	Effective coefficient of friction $\underline{\mu}$ | $\underline{Assessment}$ 0 - .25 | Good .26 - .35 | Fair > .35 | Marginal	$\underline{\mu}$ | $\underline{Assessment}$ .41 | Marginal	Pass
G.	Shall be less than Occupant Impact Velocity - ft/s (m/s) Longitudinal | Lateral 30 (9.2) | 25 (7.6) Occupant Ridedown Accelerations - g's Longitudinal | Lateral 15 | 15	Occupant Impact Velocity - ft/s (m/s) Longitudinal | Lateral 19.3 (5.9) | 24.8 (7.6) Occupant Ridedown Accelerations - g's Longitudinal | Lateral -3.7 | 12.5	Pass Pass
H.	Exit angle shall be less than 12 degrees	Exit angle was 8.2 degrees	Pass

* A, B, C, and D are required. E, F, G, and H are desired. (See table 1)

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Vehicle:	1981 Ford Single-Unit Truck
Test Inertia Weight:	18,000 lb (8 172 kg)
Empty Weight:	10,790 lb (4 899 kg)
Impact Speed:	51.6 mi/h (83.0 km/h)
Impact Angle:	14.6 deg

The vehicle impacted the transition 11 ft (3.4 m) upstream from the end of the concrete parapet. At 0.071 s after impact the front wheels received a steer input to the left, and the vehicle began to redirect at 0.118 s after impact. At 0.155 s the vehicle contacted the end of the concrete parapet, and at 0.226 s a severe steer input to the vehicle occurred. By 0.262 s the vehicle was traveling parallel to the transition at a speed of 48.9 mi/h (78.7 km/h), and at 0.341 s the rear of the vehicle impacted the transition. The vehicle lost contact with the terminal connector at 0.585 s; however, the van-box remained in contact with the top of the concrete parapet until 1.718 s after impact. Total length of contact with the transition was 18.5 ft (5.6 m) As the vehicle continued forward, it began to yaw clockwise and roll counterclockwise. The brakes were applied at 2.5 s after impact and the vehicle subsequently came to rest on its left side 165 ft (50 m) down and 45 ft (14 m) in front of the point of impact.

The transition received moderate damage (figure 97). Maximum lateral permanent deformation to the transition was 10.0 in (254 mm). The end of the concrete parapet where the terminal connector attached was cracked.

The vehicle sustained damage to the left side. Maximum crush at the left front corner at bumper height was 13.0 in (330 mm). The floor pan was pushed inward and the cab was bent and twisted. The windshield and rear glass were broken. The frame at the rear axle was bent and the van-box was twisted and torn. The driver side window was broken out and the door was jammed. Also, damage was done to the front bumper, hood, left front quarter panel, and outer left rear tire and rim. The right door was also jammed.

The transition contained the vehicle with minimal lateral movement of the transition. There was no intrusion of railing components into the occupant compartment; however, the floor pan was slightly deformed into the vehicle. The vehicle remained upright and relatively stable during the collision; however, after exiting the test installation the vehicle rolled onto its left side 45 ft (14 m) forward of the transition. The transition redirected the vehicle with the effective coefficient of friction rated as good. The vehicle trajectory at loss of contact indicated some intrusion into adjacent traffic lanes.

Performance of the transition in this test is judged acceptable, as indicated in figure 98 and table 42.
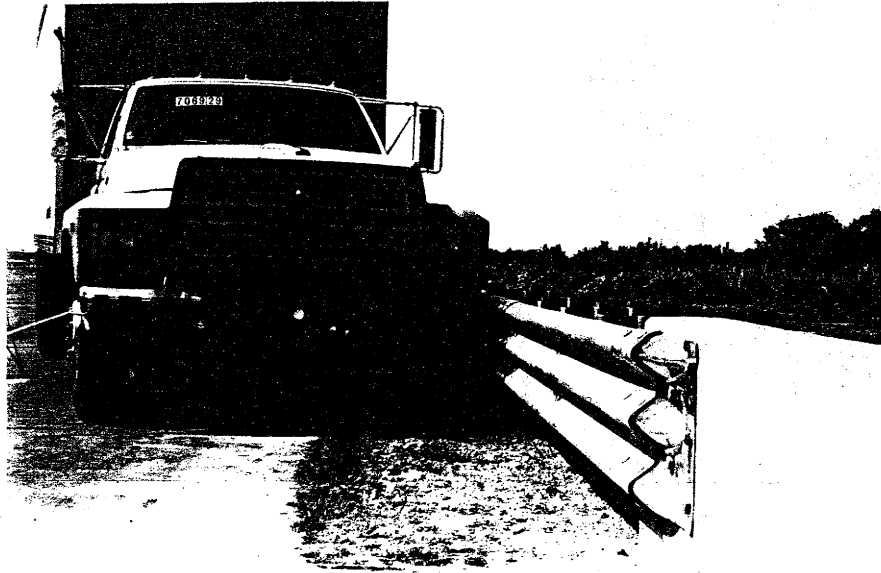
Figure 97. Vehicle and transition for test 7069-29.

0.000 s   0.181 s   0.362 s   0.542 s
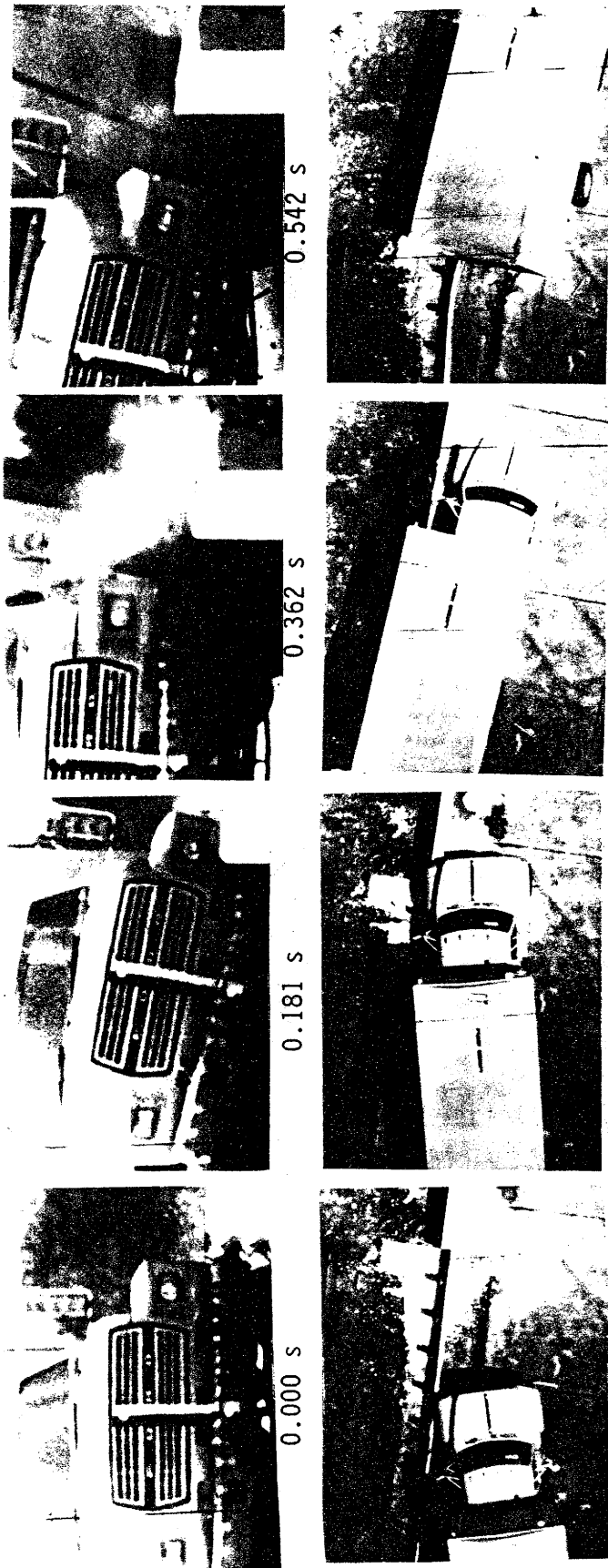
Test No. 7069-29
Date 06/05/92

Test Installation   32-in (813-mm)
                  Thrie-Beam Transition
Installation Length   . 85 ft (26 m)

Test Vehicle . . . . . . 1981 Ford
                   Single-Unit Truck

Vehicle Weight
   Empty Weight . . . . . 10,790 lb (4 899 kg)
   Test Inertia . . . . . 18,000 lb (8 172 kg)
Maximum Vehicle Crush   . 13.0 in (330 mm)

Max. Perm. Deform. . . . 10.0 in (254 mm)

Impact Speed. . . . . 51.6 mi/h (83.0 km/h)
Impact Angle. . . . . 14.6 deg
Speed at Parallel . . 48.9 mi/h (78.7 km/h)
Exit Speed . . . . . N/A
Exit Trajectory . . . 11 deg
Vehicle Accelerations
   (Max. 0.050-sec Avg) at c.g.
   Longitudinal. . . . -2.3 g
   Lateral . . . . . . 6.3 g
Occupant Impact Velocity at true c.g.
   Longitudinal. . . . 9.4 ft/s (2.9 m/s)
   Lateral . . . . . . 11.9 ft/s (3.6 m/s)
Occupant Ridedown Accelerations
   Longitudinal. . . . -4.1 g
   Lateral . . . . . . 9.0 g

2'-7"

6'-6"
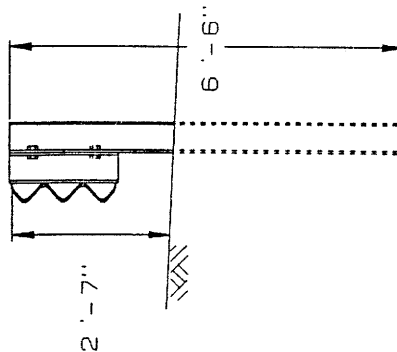
1 in = 25.4 mm
1 ft = 0.305 m

Figure 98.   Summary of results for test 7069-29.

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Table 42. Evaluation of crash test no. 7069-29.
{32-in (813-mm) thrie-beam transition [18,000 lb (8 172 kg)|51.6 mi/h (83.0 km/h)|14.6 degrees]}

CRITERIA	TEST RESULTS	PASS/FAIL*
A. Must contain vehicle	Vehicle was contained	Pass
B. Debris shall not penetrate passenger compartment	No debris penetrated passenger compartment	Pass
C. Passenger compartment must have essentially no deformation	Minimal deformation	Pass
D. Vehicle must remain upright	Vehicle remained upright during test. Rolled after exiting test site.	N/A
E. Must smoothly redirect the vehicle	Vehicle was smoothly redirected	N/A
F. Effective coefficient of friction μ Assessment 0 - .25 Good .26 - .35 Fair > .35 Marginal	μ Assessment .08 Good	N/A
G. Shall be less than Occupant Impact Velocity - ft/s (m/s) Longitudinal Lateral 30 (9.2) 25 (7.6) Occupant Ridedown Accelerations - g's Longitudinal Lateral 15 15	Occupant Impact Velocity - ft/s (m/s) Longitudinal Lateral 9.4 (2.9) 11.9 (3.6) Occupant Ridedown Accelerations - g's Longitudinal Lateral -2.3 9.0	N/A
H. Exit angle shall be less than 12 degrees	Exit angle was 11 degrees	N/A

* A, B, and C are required. D, E, F, and H are desired. (See table 1)

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CHAPTER 7. SUMMARY OF STATIC LOAD TESTS OF THRIE- AND W-BEAM TERMINAL CONNECTORS

In some railing/transition designs, more than two thicknesses of thrie- or W-beam are lapped together. One common situation where this occurs is where a double thickness of rail element is bolted to a terminal connector. The three thicknesses of material cannot be bolted together if conventional hole patterns are used. A proposed remedy for this problem is to provide slotted holes in the terminal connector with the holes slanted at about 45 degrees to the longitudinal axis of the connector. Such a hole pattern allows the three layers to be bolted together, but the strength of such a terminal connector was questioned.

Static axial load tension tests were performed on several thrie- and W-beam terminal connectors (figure 99) to determine their strengths and failure modes. The results are summarized in table 43 and additional details are presented in appendix M.
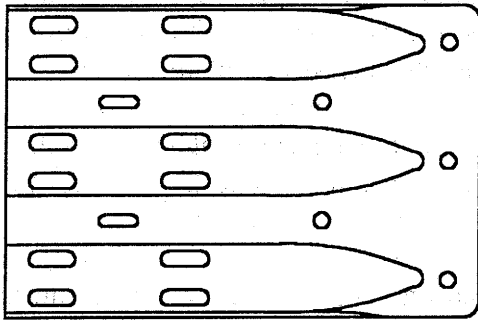
SAMPLE 1
Manufacturer #1
Thickness = 10 gauge
Splice slots – 1"X 3"
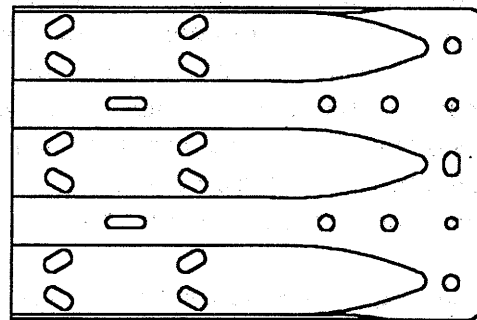
SAMPLES 2–3–4–6
Manufacturer #2
Thickness = 12 gauge
Splice slots – 1"X 1 7/8"
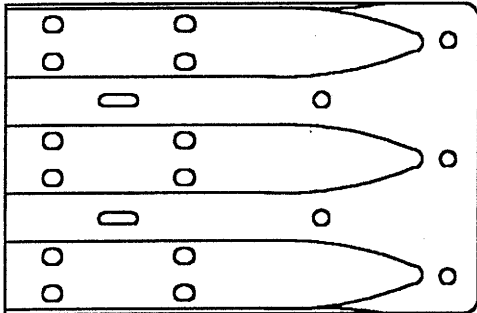
SAMPLE 5
Manufacturer #3
Thickness = 10 gauge
Splice slots – 29/32"X 1 1/8"
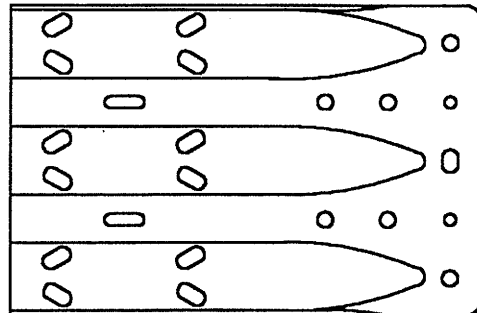
SAMPLE 7
Manufacturer #2
Thickness = 10 gauge
Splice slots – 1"X 1 7/8"

1 in = 25.4 mm

Figure 99. Terminal connector test specimens.

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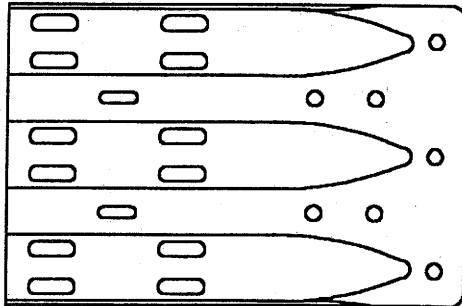
SAMPLES 8-9

Manufacturer #1
Thickness = 10 gauge
Splice slots – 1"X 3"
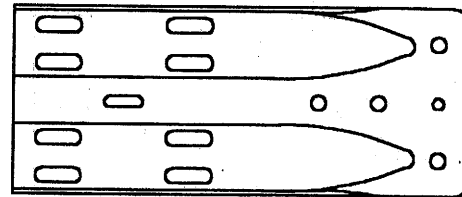
SAMPLE 12

Manufacturer #2
Thickness = 12 gauge
Splice slots – 1"X 3"
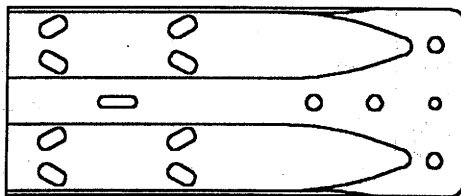
SAMPLES 10-11

Manufacturer #2
Thickness = 12 gauge
Splice slots – 1"X 1 7/8"
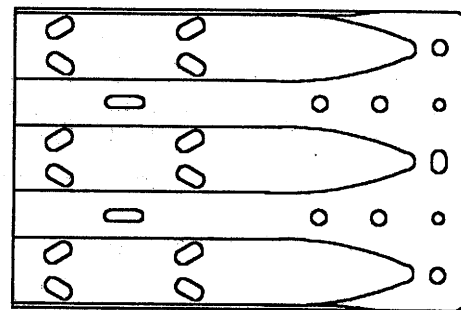
SAMPLES 13-14-15

Manufacturer #2
Thickness = 10 gauge
Splice slots – 1"X 1 7/8"

1 in = 25.4 mm

Figure 99. Terminal connector test specimens. (continued)

Table 43. Ultimate loads and properties of W-beam and thrie-beam terminal connectors.

SAMPLE NO.	MANUFACTURER	MODEL	HOLE PATTERN	THICKNESS	NO. HOLES	ULTIMATE LOAD
1	NUMBER ONE	THRIE-BEAM	ST. LONG SLOTS	10 GAUGE	5[1]	95.9 KIPS (426.6 kN)
2	NUMBER TWO	THRIE-BEAM	ANGLED SLOTS	12 GAUGE	9[2]	132.6 KIPS (589.8 kN)
3	NUMBER TWO	THRIE-BEAM	ANGLED SLOTS	12 GAUGE	9[2]	126.9 KIPS (564.5 kN)
4	NUMBER TWO	THRIE-BEAM	ANGLED SLOTS	12 GAUGE	9[2]	133.7 KIPS (594.7 kN)
5	NUMBER THREE	THRIE-BEAM	ST. SHORT SLOTS	10 GAUGE	5[1]	116.7 KIPS (519.1 kN)
6	NUMBER TWO	THRIE-BEAM	ANGLED SLOTS	12 GAUGE	9[1]	83.3 KIPS (370.5 kN)
7	NUMBER TWO	THRIE-BEAM	ANGLED SLOTS	10 GAUGE	9[1]	_[4]
8	NUMBER ONE	THRIE-BEAM	ST. LONG SLOTS	10 GAUGE	7[1]	93.8 KIPS (417.2 kN)
9	NUMBER ONE	THRIE-BEAM	ST. LONG SLOTS	10 GAUGE	7[1]	87.7 KIPS (390.1 kN)
10	NUMBER TWO	W-BEAM	ANGLED SLOTS	12 GAUGE	4[3]	65.9 KIPS (293.1 kN)
11	NUMBER TWO	W-BEAM	ANGLED SLOTS	12 GAUGE	4[3]	66.4 KIPS (295.4 kN)
12	NUMBER TWO	W-BEAM	ST. LONG SLOTS	12 GAUGE	4[3]	71.1 KIPS (316.3 kN)
13	NUMBER TWO	THRIE-BEAM	ANGLED SLOTS	10 GAUGE	9[1]	102.4 KIPS (455.5 kN)
14	NUMBER TWO	THRIE-BEAM	ANGLED SLOTS	10 GAUGE	9[1]	99.3 KIPS (441.7 kN)
15	NUMBER TWO	THRIE-BEAM	ANGLED SLOTS	10 GAUGE	9[1]	101.8 KIPS (452.8 kN)

NOTES:
1. Terminal connectors tested with 5-SAE Grade 8, 7/8-in (22-mm) bolts at the flat section.
2. Terminal connectors tested with 7-SAE Grade 8, 7/8-in (22-mm) bolts and 2-SAE Grade 8, 3/4-in (19-mm) bolts at the flat section.
3. Terminal connectors tested with 4-SAE Grade 8, 7/8-in (22-mm) bolts at the flat section.
4. Sample 7 was used in crash test 7069-29.

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CHAPTER 8. SUMMARY AND CONCLUSIONS

Bridge railing designs that satisfy requirements for each of three performance levels called for in the 1989 Guide Specifications for Bridge Railings have been designed, tested, and evaluated.[3] Three railing designs for performance level one, seven railing designs for performance level two, three railing designs for performance level three, a transition for performance level one, and a transition for performance level two have been designed, tested, and evaluated.

Recommended design criteria for each of the three performance levels have been set forth and were used in analyzing the railings evaluated herein. The criteria include magnitude, distribution, and location of collision forces in addition to geometric requirements for various impact conditions. The recommended forces with no factor of safety (i.e., load factor = 1.0) are used in ultimate strength analysis procedures. Railings designed by this procedure have been found to be generally adequate and have shown little or no structural distress in full-scale crash tests.

REFERENCES

1. *Standard Specifications for Highway Bridges*, 13ᵗʰ Edition, American Association of State Highway and Transportation Officials (AASHTO), Washington, DC, 1983.

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Contracting Officer's Technical Representative (COTR) - Charles F. McDevitt

16. Abstract

The 32-in (813-mm) F-shape concrete parapet is similar to the New Jersey safety shape. The F-shape was designed and tested to performance level two of the 1989 *Guide Specifications for Bridge Railings* and acceptable performance was obtained. Computed ultimate strength of the railing with the steel reinforcement used was 59 kips (263 kN).

This volume is the seventh in a series. The other volumes in the series are: Volume I: Technical Report; Volume II: Appendix A, "Oregon Side Mounted Bridge Railing;" Volume III: Appendix B, "BR27D Bridge Railing;" Volume IV: Appendix C, "Illinois 2399-1 Bridge Railing;" Volume V: Appendix D, "32-in (813-mm) (813-mm) Concrete Parapet Bridge Railing;" Volume VI: Appendix E, "32-in (813-mm) (813-mm) New Jersey Safety Shape;" Volume VIII: Appendix G, "BR27C Bridge Railing;" Volume IX: Appendix H, "Illinois Side Mount Bridge Rail;" Volume X: Appendix I, "42-in (1.07-m) Concrete Parapet Bridge Railing;" Volume XI: Appendix J, "42-in (1.07-m) F-Shape Bridge Railing;" Volume XII: Appendix K, "Oregon Transition;" Volume XIII: Appendix L, "32-in (813-mm) (813-mm) Thrie-Beam Transition;" and Volume XIV: Appendix M, "Axial Tensile Strength of Thrie and W-Beam Terminal Connectors."

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Form DOT F 1700.7 (8-69)

SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH				
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
AREA				
in²	square inches	645.2	square millimeters	mm²
ft²	square feet	0.093	square meters	m²
yd²	square yards	0.836	square meters	m²
ac	acres	0.405	hectares	ha
mi²	square miles	2.59	square kilometers	km²
VOLUME				
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft³	cubic feet	0.028	cubic meters	m³
yd³	cubic yards	0.765	cubic meters	m³

NOTE: Volumes greater than 1000 l shall be shown in m³

Symbol	When You Know	Multiply By	To Find	Symbol
MASS				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
TEMPERATURE (exact)				
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celcius temperature	°C
ILLUMINATION				
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m²	cd/m²
FORCE and PRESSURE or STRESS				
lbf	poundforce	4.45	newtons	N
lbf/in²	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH				
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
AREA				
mm²	square millimeters	0.0016	square inches	in²
m²	square meters	10.764	square feet	ft²
m²	square meters	1.195	square yards	yd²
ha	hectares	2.47	acres	ac
km²	square kilometers	0.386	square miles	mi²
VOLUME				
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m³	cubic meters	35.71	cubic feet	ft³
m³	cubic meters	1.307	cubic yards	yd³
MASS				
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
TEMPERATURE (exact)				
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F
ILLUMINATION				
lx	lux	0.0929	foot-candles	fc
cd/m²	candela/m²	0.2919	foot-Lamberts	fl
FORCE and PRESSURE or STRESS				
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in²

(Revised September 1993)

* SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.

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CHAPTER 1. DESIGN OF RAILING

The 32-in (813-mm) F-shape was originally designed to meet performance level two of the proposed 1987 version of the *Guide Specifications for Bridge Railings*.[1] The required strength test from that proposed version was 5,400-lb (2 452-kg) pickup traveling at 65 mi/h (105 km/h) and impacting at 20 degrees. The design force used for this test condition was 56 kips (249 kN) of line load uniformly distributed over 42 in (1.07 m) at 24 in (610 mm) above the deck surface. The railing was eventually tested to performance level two requirements of the 1989 *Guide Specifications for Bridge Railings* which requires strength test conditions of 18,000 lb (8 172 kg)|50 mi/h (80.5 km/h)|15 degrees).[2] The design force for this condition is 56 kips (249 kN) of line load uniformly distributed over 42 in (1.07 m) at 29 in (737 mm) above the deck surface.

A cross section of the railing design is shown in figure 1. Total height of the F-shape is 32 in (813 mm). It has a lower 3-in (76-mm) high vertical section, a middle 7-in (177-mm) high inclined surface of 55 degrees, and an upper 22-in (559-mm) high inclined surface of 84 degrees. It has a bottom width of 14.7 in (373 mm) and a top width of 7.5 in (191 mm). The slope at the bottom of the rail serves to limit the damage done to vehicles impacting at low angles by causing the front tire to ride up on the rail and redirect itself back to the pavement. A thickened portion at the top of the rail serves to increase the longitudinal distribution of force within the F-shape and allow more length of F-shape and deck to resist the collision force.

Eight #4 longitudinal bars were used in the F-shape. The vertical steel was #5 rebars at 8-in (200-mm) spacing. Specified concrete strength was 3,600 psi (34 800 kPa) at 28 days and specified steel yield was 40,000 psi (275 600 kPa). The cantilevered deck was supported on a foundation so that the deck overhang was 39 in (990 mm).

The strength of the railing was computed using yieldline analysis procedures.[3] The strength computations are presented on the following pages. The analysis predicts the length of the failure mechanism to be 8.3 ft (2.5 m) and the total ultimate load capacity to be 59 kips (262 kN). The analysis also shows that the yield lines are confined to the F-shape rather than extending into the bridge deck.

GRADE 40 REINFORCING STEEL
3600 PSI CONCRETE

14¾"

4⅞"   7½"

32"

12"

1½"

1½"

8 #4 LONGIT. BARS

1½"

#5 @ 4¾" C-C

#5 @ 8" C-C
#5 @ 8" C-C

7"

3"

1½"

2"

8"

1¼"

6 #5 LONGIT. BARS

#4 @ 9½" C-C

1"

TEST INSTALLATION OVERHANG = 39"

1 in = 25.4 mm
1 psi = 6.89 kPa
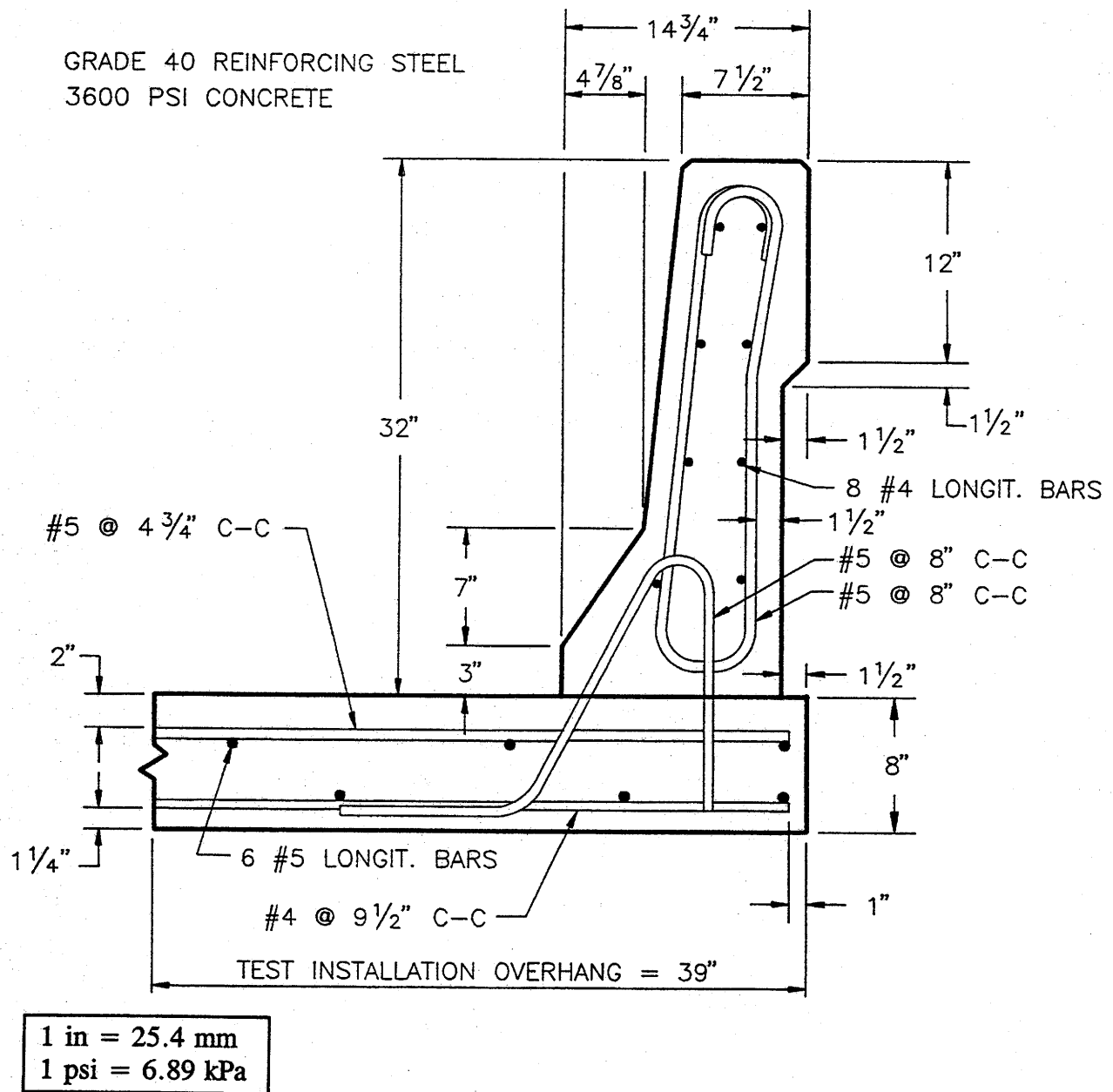
Figure 1. 32-in (813-mm) F-shape bridge railing.

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CHAPTER 2. CRASH TEST PROCEDURES

The 32-in (813-mm) F-shape bridge railing was tested to performance level two requirements.[1] The following nominal test conditions were used:

1,800-lb (817-kg) passenger car | 60 mi/h (96.6 km/h) | 20 degrees (test 7069-3)
5,400-lb (2 452-kg) pickup | 65 mi/h (104.7 km/h) | 20 degrees (test 7069-4)
18,000-lb (8 172-kg) single-unit truck | 50 mi/h (80.5 km/h) | 15 degrees (tests 7069-8, 9, 11)

Each vehicle was instrumented with three solid-state angular rate transducers to measure yaw, pitch, and roll rates and a triaxial accelerometer mounted near the center-of-gravity. In addition, the pickup and 18,000-lb (8 172-kg) trucks were instrumented with two biaxial accelerometers: one mounted forward of the center-of-gravity and one mounted in the rear of the vehicle. The accelerometers were strain gauge type with a linear millivolt output proportional to acceleration. The electronic signals from the accelerometers and transducers were transmitted to a base station by means of constant bandwidth FM/FM telemetry link for recording on magnetic tape and for display on a real-time strip chart. Provision was made for transmission of calibration signals before and after each test, and an accurate time reference signal was simultaneously recorded with the data.

Pressure sensitive contact switches on the bumper of each vehicle were actuated just prior to impact by wooden dowels to indicate elapsed time over a known distance and provide a measurement of impact velocity. Each initial contact also produced an "event" mark on the data record to establish the instant of impact. Data from the electronic transducers were digitized using a microcomputer for analysis and evaluation of performance.

The multiplex of data channels transmitted on one radio frequency was received at a data acquisition station and demultiplexed into separate tracks of Intermediate Range Instrumentation Group (I.R.I.G.) tape recorders. After the test, the data were played back from the tape machines, filtered with an SAE J211 filter, and digitized using a microcomputer for analysis and evaluation of performance.

Alderson Research Laboratories Hybrid II, 50th percentile anthropomorphic dummies were used in the passenger car and the pickup. One uninstrumented dummy was placed in the driver position of the automobile and two uninstrumented dummies were placed in the pickup truck--one in the driver seat and one in the passenger seat. No dummies were placed in the single-unit truck. Each dummy was restrained with standard restraint equipment seat belts. No dummies were carried in the single-unit trucks.

The digitized data obtained from the electronic transducers were then processed using two computer programs: DIGITIZE and PLOTANGLE. Brief descriptions on the functions of these two computer programs are as follows.

The DIGITIZE program uses digitized data from vehicle-mounted linear accelerometers to compute occupant/compartment impact velocities, time of occupant/compartment impact after vehicle impact, highest 0.010-s averages of vehicle

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acceleration after occupant/compartment impacts, and time of highest 0.010-s averages. The DIGITIZE program also calculates a vehicle impact velocity and the change in vehicle velocity at the end of a given impulse period. In addition, maximum average accelerations over a 0.050-s intervals in each of three directions are computed. Acceleration versus time curves for the longitudinal, lateral, and vertical directions are then plotted from the digitized data of the vehicle-mounted linear accelerometers using a commercially available software package (QUATTRO PRO). For each of these graphs, a 0.050-s average window was calculated at the center of each 0.050-s interval and then plotted with the first 0.050-s average plotted at 0.026 s.

The PLOTANGLE program uses the digitized data from yaw, pitch, and roll rate charts to compute angular displacements in degrees at 0.001-s intervals and then instructs a plotter to draw a reproducible plot of yaw, pitch, and roll versus time. It should be noted that these angular displacements are sequence dependent with the sequence yaw, pitch, and roll for the data presented herein. These displacements are in reference to the vehicle-fixed coordinate system with the initial position and orientation of the vehicle-fixed coordinate system being that which existed at initial impact.

Photographic coverage of the tests included three high-speed cameras: one over head with a field of view perpendicular to the ground and directly over the impact point, one placed to have a field of view parallel to and aligned with the railing system at the downstream end, and a third placed perpendicular to the front of the railing system. In the passenger car and pickup tests, a high-speed camera was placed onboard the vehicle to record the actions of the dummy(ies) during the test. A flash bulb activated by pressure sensitive tape switches was positioned on the impacting vehicle to indicate the instant of contact with the railing system and was visible from each camera. The films from these high-speed cameras were analyzed on a computer-linked motion analyzer to observe phenomena occurring during the collision and to obtain time-event, displacement, and angular data. A 16-mm movie cine, a professional video camera, and a 3/4-in (19 mm) video recorder along with 35-mm cameras were used for documentary purposes and to record conditions of the test vehicle and railing system before and after the test.

The passenger car and pickup were towed into the test installation using a steel cable guidance and reverse two system. A steel cable for guiding the test vehicle was stretched along the path, anchored at each end, and threaded through an attachment to the front wheel of the test vehicle, passed around a pulley near the impact point, through a pulley on the tow vehicle, and then anchored to the ground such that the tow vehicle moved away from the test site. A 2-to-1 speed ratio between the test and tow vehicle existed with this system. Immediately prior to impact with the railing system, the test vehicle was released to be free-wheeling and unrestrained. The vehicle remained free-wheeling, i.e., no steering or braking inputs, until the vehicle cleared the immediate area of the test site. At this time brakes on the vehicle were activated to bring the vehicle to a safe and controlled stop.

The 18,000-lb (8 172-kg) trucks were guided into the test installation using a remote controlled guidance system. Due to mechanical and instrumentation failures during the first two tests with the 18,000-lb (8 172-kg) truck, the nominal test speed of 50 mi/h (80.5 km/h)

was not attained, requiring a total of three tests to be performed to acquire the required speed.

CHAPTER 3. FULL-SCALE CRASH TESTS

TEST 7069-3

Test Description

The 1980 Honda (see figure 2) was directed into the 32-in (813-mm) F-shape bridge railing (figure 3) using a cable reverse tow and guidance system. Test inertia mass of the vehicle was 1,800 lb (817 kg) and its gross static mass was 1,966 lb (893 kg). The height to the lower edge of the vehicle bumper was 14.0 in (356 mm) and it was 19.5 in (495 mm) to the top of the bumper. Other dimensions and information on the test vehicle are given in figure 4. The vehicle was free-wheeling and unrestrained just prior to impact.

The speed of the vehicle at impact was 60.1 mi/h (96.7 km/h) and the angle of impact was 21.4 degrees. The vehicle impacted the bridge railing at midlength. At approximately 0.025 s after impact the right front tire began to ride up the concrete face of the bridge railing, and by 0.034 s the vehicle began to redirect. As the vehicle continued forward, the right side of the vehicle continued to ride up the face of the bridge railing, and at 0.186 s the left front wheel left the ground. The rear of the vehicle hit the railing at 0.189 s, and at 0.271 s the vehicle was parallel with the railing. The vehicle lost contact with the railing at 0.276 s after impact. As the vehicle exited the railing, it had a yaw angle of 0.9 degree and a trajectory path of 6.2 degrees. The vehicle brakes were applied and the vehicle subsequently came to rest 209 ft (64 m) downstream and 27 ft (8 m) behind the point of impact.

As can be seen in figure 5, the bridge railing received cosmetic damage only. There were tire marks on the face of the bridge railing indicating the vehicle rose a maximum height of about 27 in (686 mm). The vehicle was in contact with the bridge railing for 10.3 ft (3.1 m).

The vehicle sustained extensive damage to the right front as shown in figure 6. Maximum crush at the right front corner at bumper height was 9.0 in (229 mm). The right front and right rear wheel rims were bent and the wheel assembly and suspension damaged. The passenger door was bent and jammed and the right side was dented and scraped. The hood was bent and shifted to the left. The windshield frame was bent and the windshield was cracked. The roof of the vehicle was buckled and twisted.

Test Results

Impact speed was 60.1 mi/h (96.7 km/h) and the angle of impact was 21.4 degrees. The exit speed at time of contact (0.276 s) was 53.0 mi/h (85.3 km/h) and the vehicle trajectory path was 6.2 degrees with a vehicle yaw angle of 0.9 degree. The effective coefficient of friction was calculated to be 0.33. Occupant impact velocity was 19.0 ft/s (5.8 m/s) in the longitudinal direction and 23.7 ft/s (7.2 m/s) in the lateral direction. The highest 0.010-s occupant ridedown accelerations were -2.1 g (longitudinal) and 4.9 g (lateral). These data and other pertinent information from the test are summarized in figure 7.

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Sequential photographs of the test are shown in figures 8 and 9. Vehicular angular displacements are displayed in figure 10. Vehicular acceleration versus time traces filtered with SAE J211 filters are presented in figures 11, 12, and 13. These data were further analyzed to obtain 0.050-s average accelerations versus time. A 0.050-s interval immediately prior to impact was averaged to establish zero acceleration. The data were then processed with a moving 0.050-s average window with the first 0.050-s average plotted at 0.026 s for each trace. The maximum 0.050-s averages were -8.0 g (longitudinal) and 12.8 g (lateral).

Conclusions

The 32-in (813-mm) F-shape bridge railing contained and smoothly redirected the vehicle with no lateral movement of the bridge railing. There were no debris or detached elements. There was no intrusion into the occupant compartment although some deformation of the compartment occurred. The vehicle trajectory at loss of contact indicated minimum intrusion into adjacent traffic lanes. The vehicle remained upright and stable during the entire test period. See table 1 for a more detailed description.

Figure 2. Vehicle before test 7069-3.
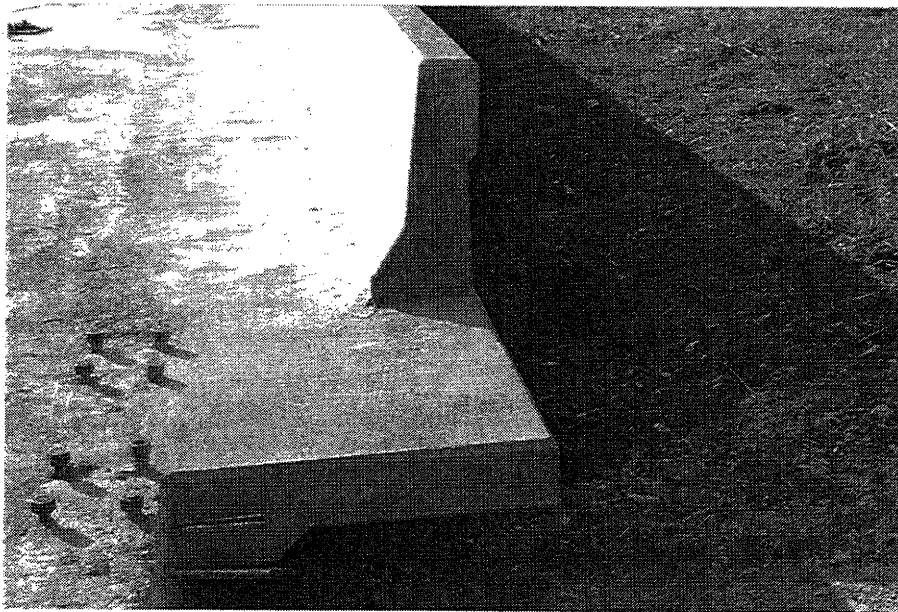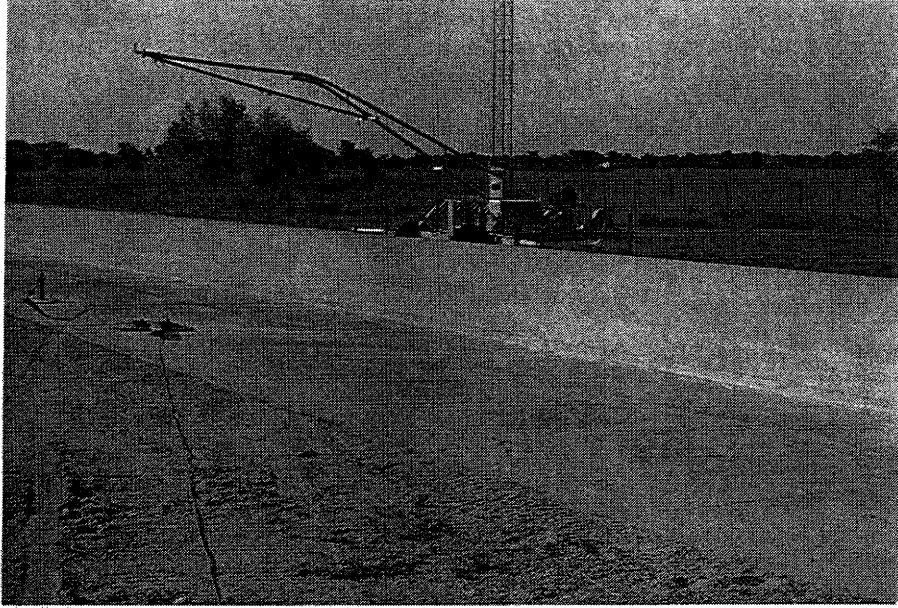
Figure 3. 32-in (813-mm) F-shape bridge railing before test 7069-3.

Date: 7-27-87   Test No.: 7069-3   VIN: SL-C1004546

Make: Honda   Model: 1300DX   Year: 1980   Odometer: 99620

Tire Size: P155/80R12   Ply Rating: 1   Bias Ply: ___   Belted: ___   Radial: X

Tire Condition: good ___
fair X
badly worn ___

Vehicle Geometry - inches

a	60 1/2	b	29 1/2
c	88	d*	52 1/2
e	28 1/4	f	146
g*	19.9	h	34.2
i	----	j	29 1/2
k	15	ℓ	27
m	19 1/2	n	3
o	14	p	53 3/4
r	22 1/4	s	13 1/4

Engine Type: _____
Engine CID: _____
Transmission Type:
   Automatic or Manual
   FWD or RWD or 4WD
Body Type: _____
Steering Column Collapse
   Mechanism:
   ___ Behind wheel units
   ___ Convoluted tube
   ___ Cylindrical mesh units
   ___ Embedded ball
   ___ NOT collapsible
   ___ Other energy absorption
   ___ Unknown

Brakes:
   Front: disc___ drum___
   Rear: disc___ drum___

4-wheel weight for c.g. det.   ℓf 550   rf 550   ℓr 353   rr 347

Mass - pounds	Curb	Test Inertial	Gross Static
M₁		1100	612
M₂		700	568
M_T		1800	1966

Note any damage to vehicle prior to test:

_____

_____

*d = overall height of vehicle
*g = measured from identical vehicle (7069-1)

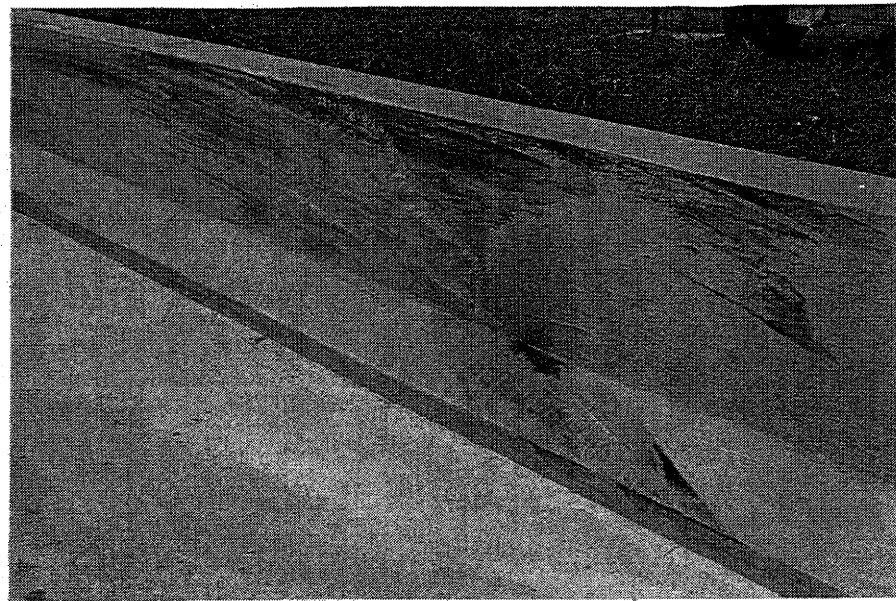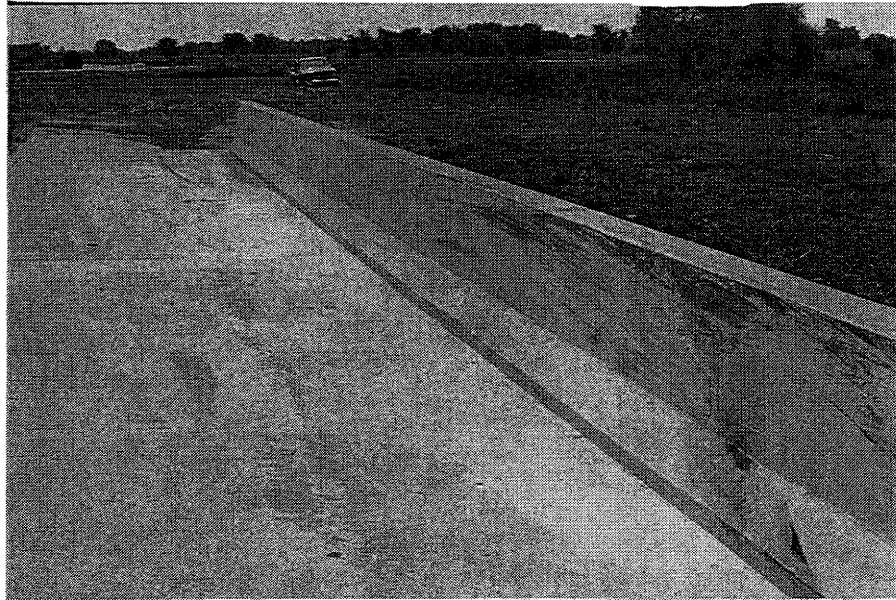| 1 in = 25.4 mm |
| 1 lb = 0.454 kg |

Figure 4.   Vehicle properties for test 7069-3.

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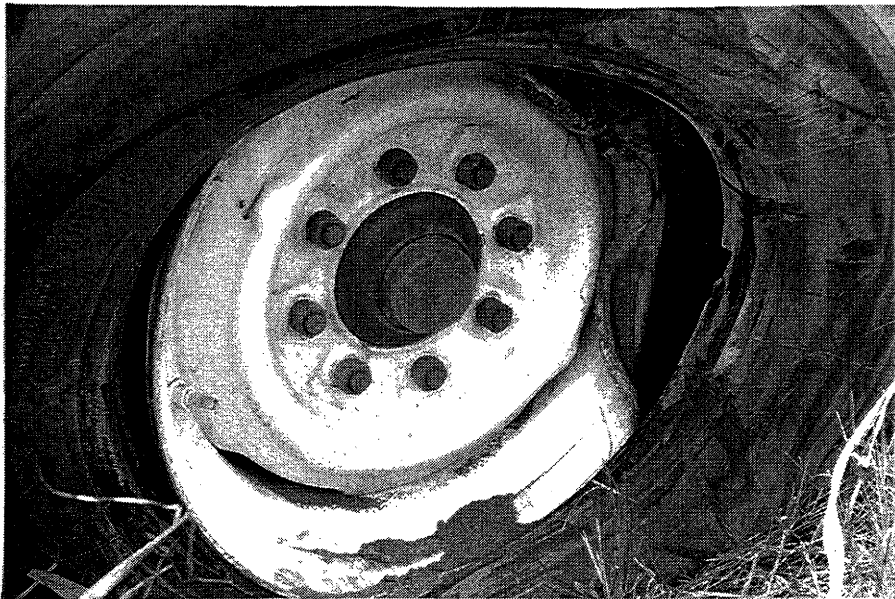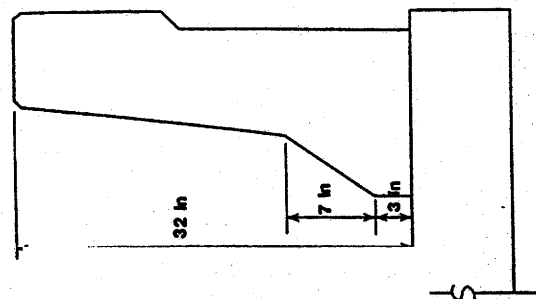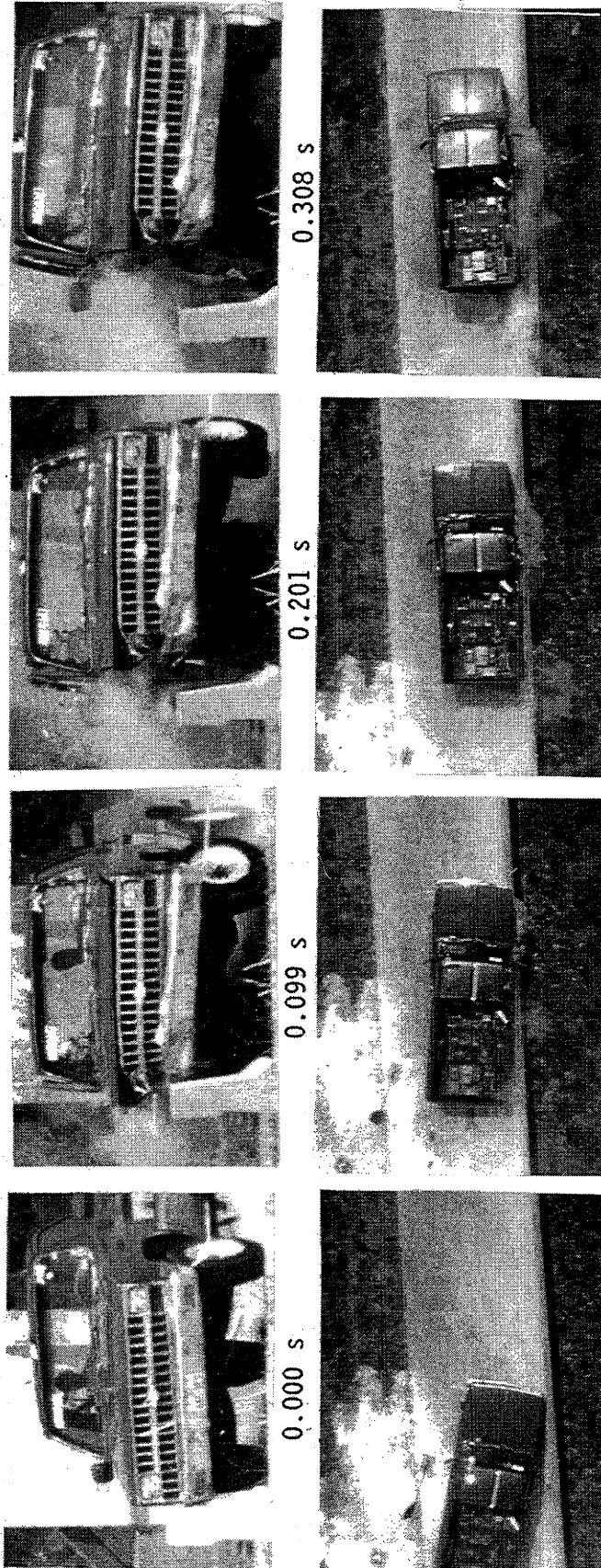Figure 5. 32-in (813-mm) F-shape bridge railing after test 7069-13.
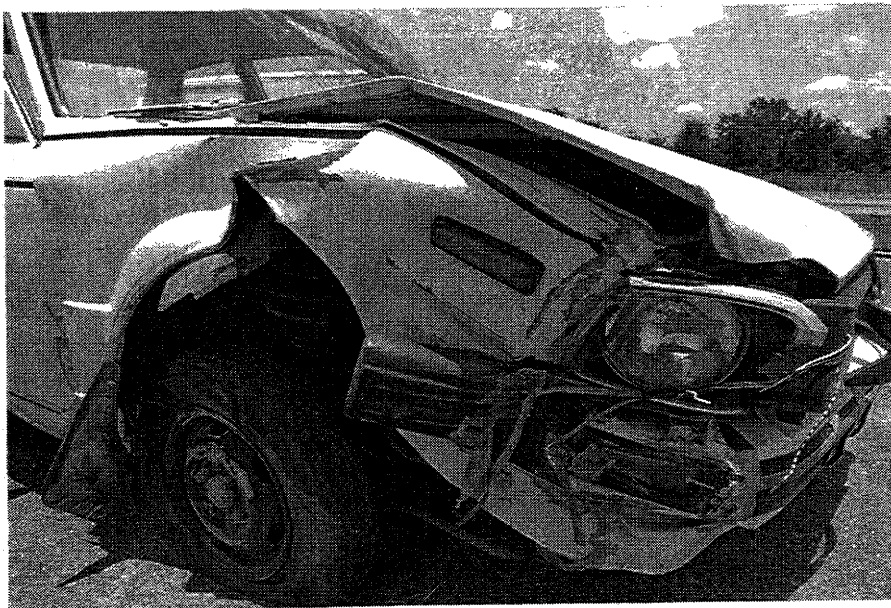
Figure 6. Vehicle after test 7069-3.

Test No.	7069-3
Date	7/28/87
Test Installation . . .	32-in (813-mm) F-Shape Bridge Railing
Installation Length . .	100 ft (30 m)
Vehicle	1980 Honda 1300 DX
Vehicle Weight	
Test Inertia	1,800 lb (817 kg)
Gross Static	1,966 lb (893 kg)
Vehicle Damage Classification	
TAD	01RFQ4
CDC	01FREK3 & 01RFEW4
Maximum Vehicle Crush .	9.0 in (229 mm)

Impact Speed. . . .	60.1 mi/h (96.7 km/h)
Impact Angle. . . .	21.4 deg
Exit Speed. . . .	53.0 mi/h (85.3 km/h)
Exit Trajectory .	6.2 deg
Vehicle Accelerations	
(Max. 0.050-sec Avg)	
Longitudinal. . .	-8.0 g
Lateral . . .	12.8 g
Occupant Impact Velocity	
Longitudinal. .	19.0 ft/s (5.8 m/s)
Lateral . . .	23.7 ft/s (7.2 m/s)
Occupant Ridedown Accelerations	
Longitudinal. .	-2.1 g
Lateral . . .	4.9 g

Figure 7. Summary of results for test 7069-3.
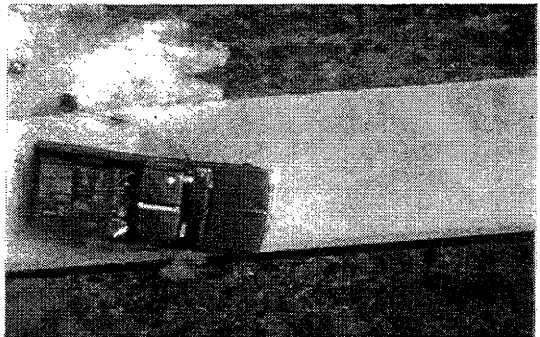
(1 in = 25.4 mm)

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Table 1. Evaluation of crash test no. 7069-3.

{32-in (81-cm) F-Shape Bridge Railing [1,800 lb (817 kg)|60.1 mi/h (96.7 km/h)|21.4 degrees]}

	CRITERIA	TEST RESULTS	PASS/FAIL*
A.	Must contain vehicle	Vehicle was contained	Pass
B.	Debris shall not penetrate passenger compartment	No debris penetrated passenger compartment	Pass
C.	Passenger compartment must have essentially no deformation	Acceptable deformation	Pass
D.	Vehicle must remain upright	Vehicle remained upright	Pass
E.	Must smoothly redirect the vehicle	Vehicle was smoothly redirected	Pass
F.	Effective coefficient of friction μ Assessment 0 - .25 Good .26 - .35 Fair > .35 Marginal	μ Assessment .33 Fair	Pass
G.	Shall be less than Occupant Impact Velocity - ft/s (m/s) Longitudinal 30 (9.2) Lateral 25 (7.6) Occupant Ridedown Accelerations - g's Longitudinal 15 Lateral 15	Occupant Impact Velocity - ft/s (m/s) Longitudinal 19.0 (5.8) Lateral 23.7 (7.2) Occupant Ridedown Accelerations - g's Longitudinal -2.1 Lateral 4.9	Pass
H.	Exit angle shall be less than 12 degrees	Exit angle was 6.2 degrees. (See table 2)	Pass

* A, B, C, D and G are required. E, F, and H are desired.

Table 2. Bridge railing performance levels and crash test criteria
(Guide Specifications for Bridge Railings, proposed).[1]

PERFORMANCE LEVELS		TEST SPEEDS -- mph [1,2]			
		TEST VEHICLE DESCRIPTIONS AND IMPACT ANGLES			
		Small Automobile W = 1.8 Kips A = 5.4' B = 5.5' H_{cg} = 19" θ = 20 deg.	Pickup Truck W = 5.4 Kips A = 8.9' B = 6.5' H_{cg} = 33" θ = 20 deg.	Intercity Bus (loose ballast) W = 40.0 Kips A = 23.2' B = 8.0' H_{cg} = 56" θ = 15 deg.	Van-Type Tractor-Trailer[4] No. 2 W = 80.0 Kips A = 13.1' B = 8.0' H_{cg} = 72" R = 0.58 θ = 15 deg.
PL-1		50	45		
PL-2		60	65		
PL-3		60	65	60	-
PL-4		60	65		55
CRASH TEST EVALUATION CRITERIA[3]	Required	a,b,c,d,g	a,b,c,d	a,b,c,d	a,b,c
	Desirable[5]	e,f,h	e,f,g,h	e,f,h	d,e,f,h

Notes:

1. Except as noted, all full-scale tests shall be conducted and reported in accordance with the requirements in NCHRP Report No. 230. In addition, the maximum loads that can be transmitted from the bridge railing to the bridge deck are to be determined from static force measurements or ultimate strength analysis and reported.

2. Permissible tolerances on the test speeds and angles are as follows:

   Speed -1.0 mph +2.5 mph
   Angle -1.0 deg. +2.5 deg.

   Tests that indicate acceptable railing performance but that exceed the allowable upper tolerances will be accepted.

3. Criteria for evaluating bridge railing crash test results are as follows:

   a. The test article shall contain the vehicle; neither the vehicle nor its cargo shall penetrate or go over the installation. Controlled lateral deflection of the test article is acceptable.

   b. Detached elements, fragments, or other debris from the test article shall not penetrate or show potential for penetrating the passenger compartment or present undue hazard to other traffic.

   c. Integrity of the passenger compartment must be maintained with no intrusion and essentially no deformation.

   d. The vehicle shall remain upright during and after collision.

Table 2. Bridge railing performance levels and crash test criteria
(Guide Specifications for Bridge Railings, proposed continued).[1]

<u>Notes (cont.):</u>

e. The test article shall smoothly redirect the vehicle. A redirection is deemed smooth if the rear of the vehicle or, in the case of a combination vehicle, the rear of the tractor or trailer does not yaw more than 5 degress away from the railing from time of impact until the vehicle separates from the railing.

f. The smoothness of the vehicle-railing interaction is further assessed by the effective coefficient of friction μ:

μ	Assessment
0 - 0.25	Good
0.26 - 0.35	Fair
>0.35	Marginal

where $\mu = (\cos\theta - V_p/V)/\sin\theta$

g. The impact velocity of a hypothetical front-seat passenger against the vehicle interior, calculated from vehicle accelerations and 2.0-ft. longitudinal and 1.0-ft. lateral displacements, shall be less than:

Occupant Impact Velocity - fps	
Longitudinal	Lateral
30	25

and the vehicle highest 10-ms average accelerations subsequent to the instant of hypothetical passenger impact should be less than:

Occupant Ridedown Accelerations - g's	
Longitudinal	Lateral
15	15

h. Vehicle exit angle from the barrier shall not be more than 12 degrees. Within 100 ft. after losing contact with the railing, the vehicle shall move no more than 20 ft. plus the vehicle width from the line of the traffic face of the railing. The brakes shall not be applied until the vehicle has traveled at least 100 ft. from the point of initial impact.

4. Values A and R are estimated values describing the test vehicle and its loading. Values of A and R are described in the figure below and calculated as follows:
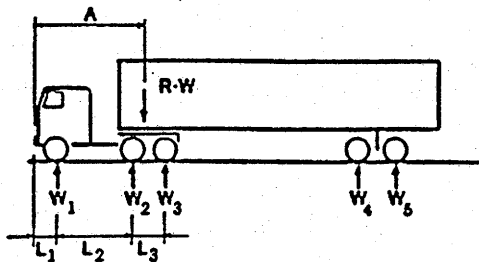
$$A = L_1 + \frac{W_2 L_2 + W_3 (L_2 + L_3)}{W_1 + W_2 + W_3}$$

$$R = \frac{W_1 + W_2 + W_3}{W}$$

$$W = W_1 + W_2 + W_3 + W_4 + W_5$$

= total vehicle weight.

5. Test articles that do not meet the desirable evaluation criteria shall have their performance evaluated by a designated authority that will decide whether the test article is likely to meet its intended use requirements.

| 1 kip = 4.45 kN |
| 1 mi/h = 1.609 km/h |
| 1 ft = 0.305 m |
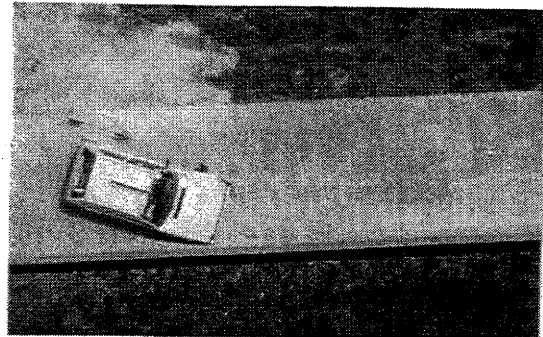
0.000 s
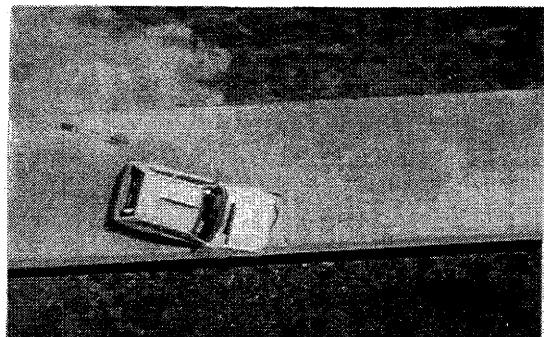
0.050 s
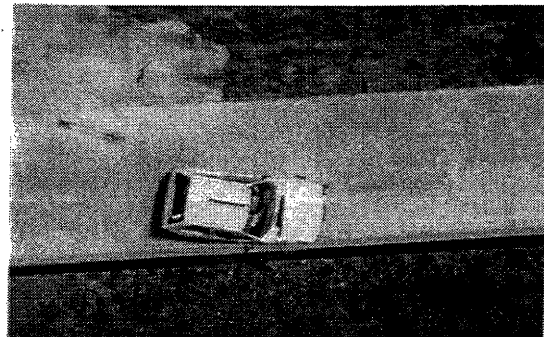
0.101 s
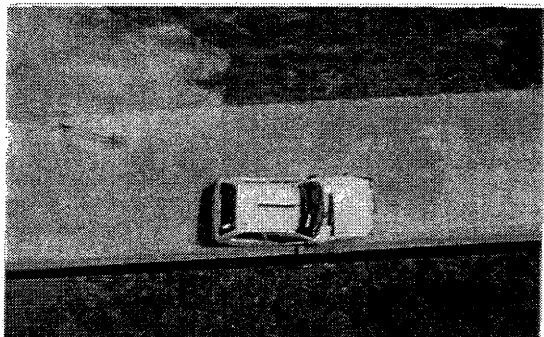
0.151 s

Figure 8.   Sequential photographs for test 7069-3.

18
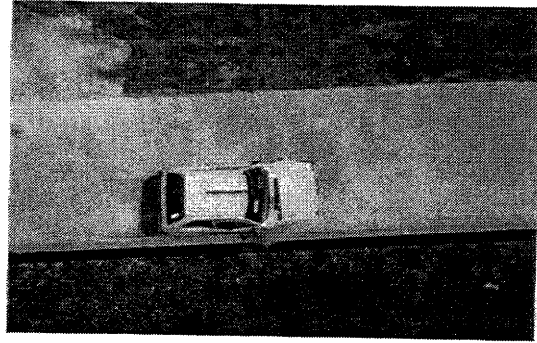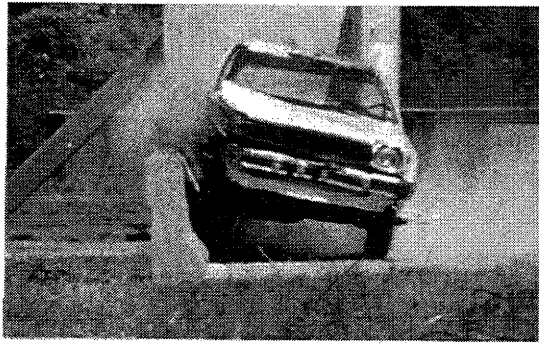
0.201 s
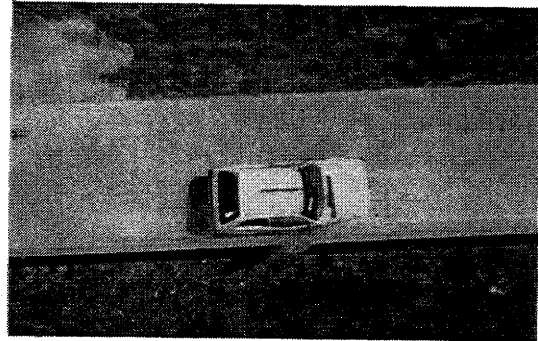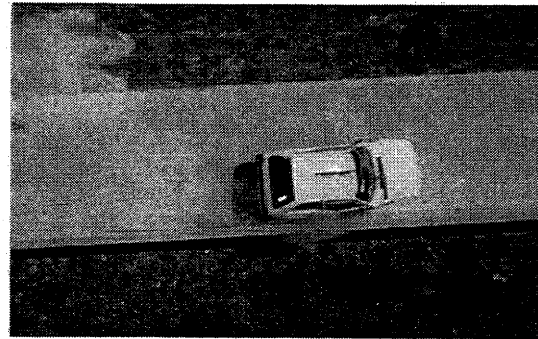
0.252 s

0.302 s
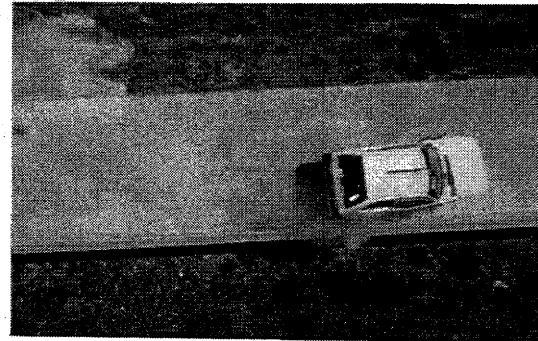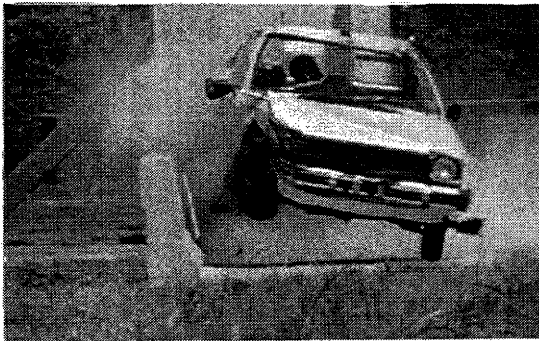
0.372 s

Figure 8. Sequential photographs for test 7069-3 (continued).

19
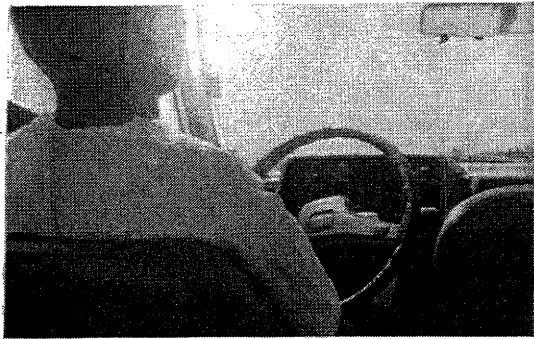
0.000 s

0.206 s
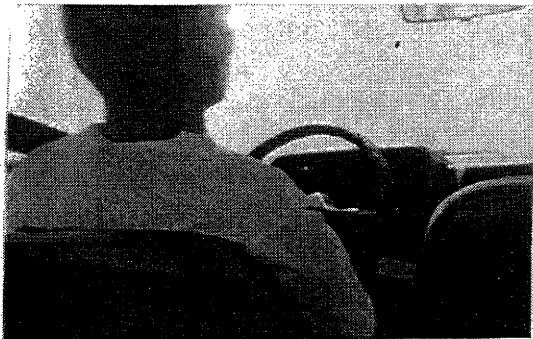
0.046 s

0.252 s

0.103 s

0.298 s

0.149 s

0.367 s

Figure 9. Interior sequential photographs for test 7069-3.
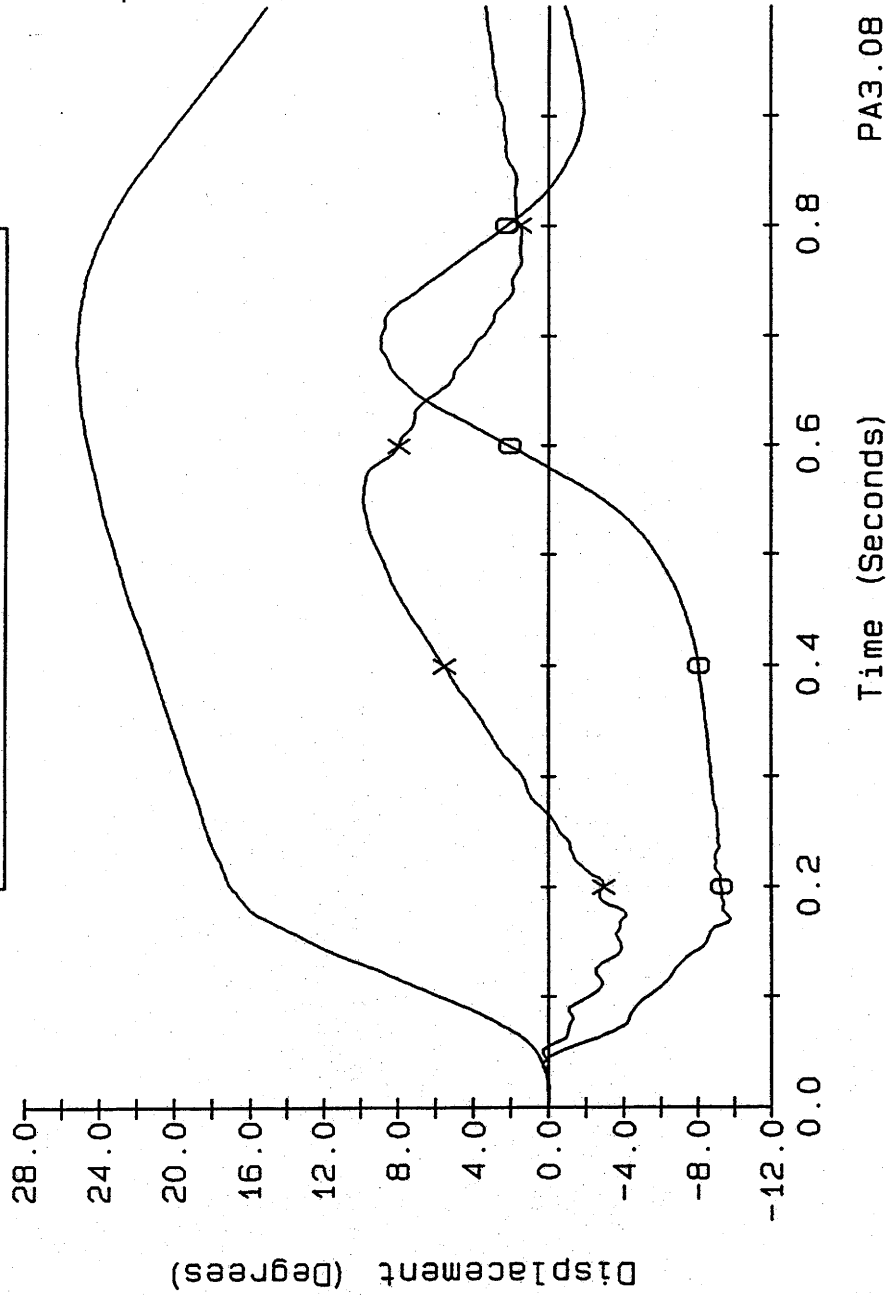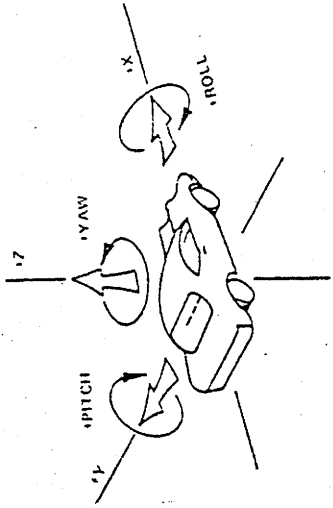
20

Figure 10. Vehicle angular displacements for test 7069-3.

21
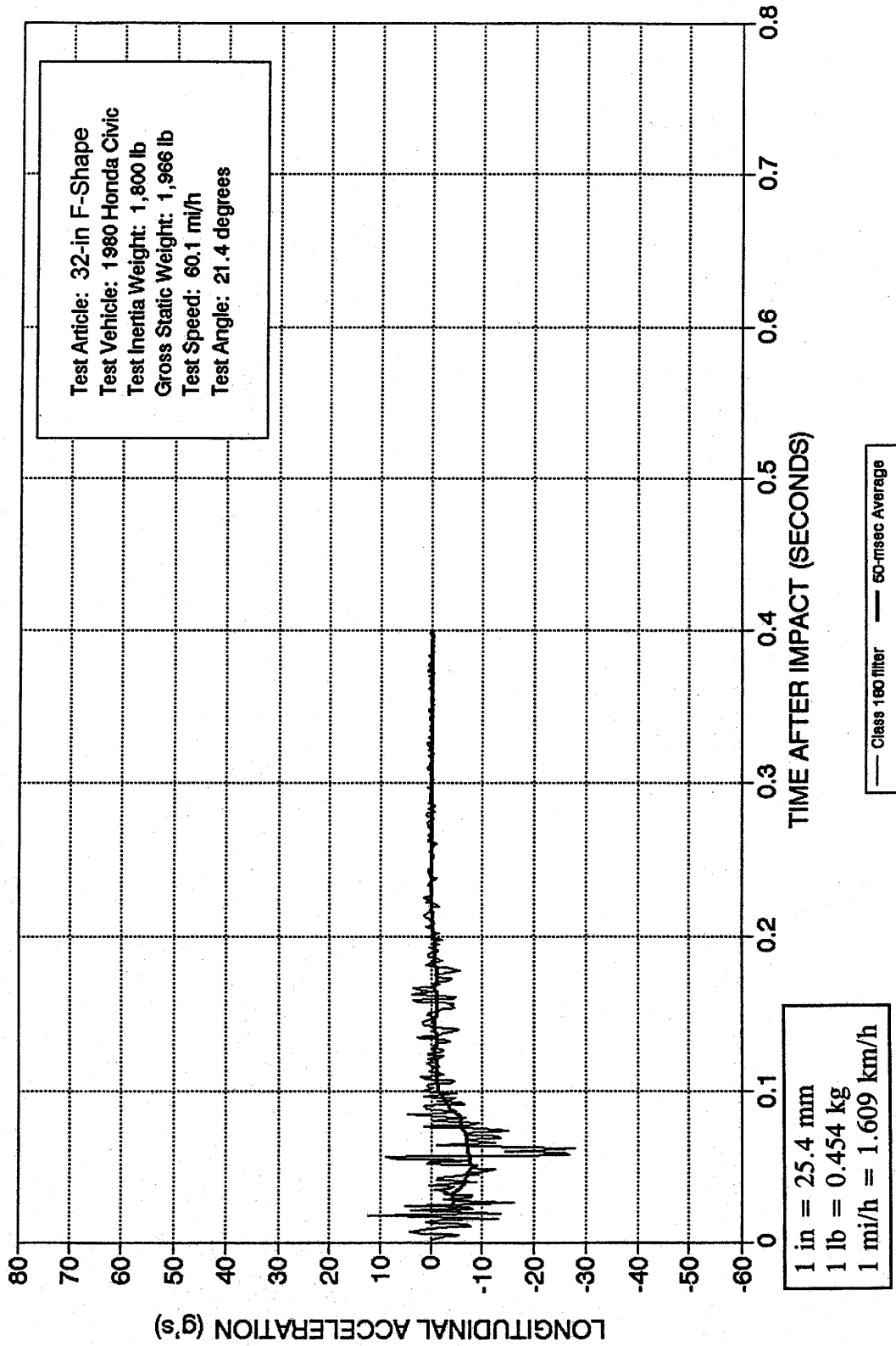
Figure 11. Vehicle longitudinal accelerometer trace for test 7069-3 (accelerometer located near center-of-gravity).

22
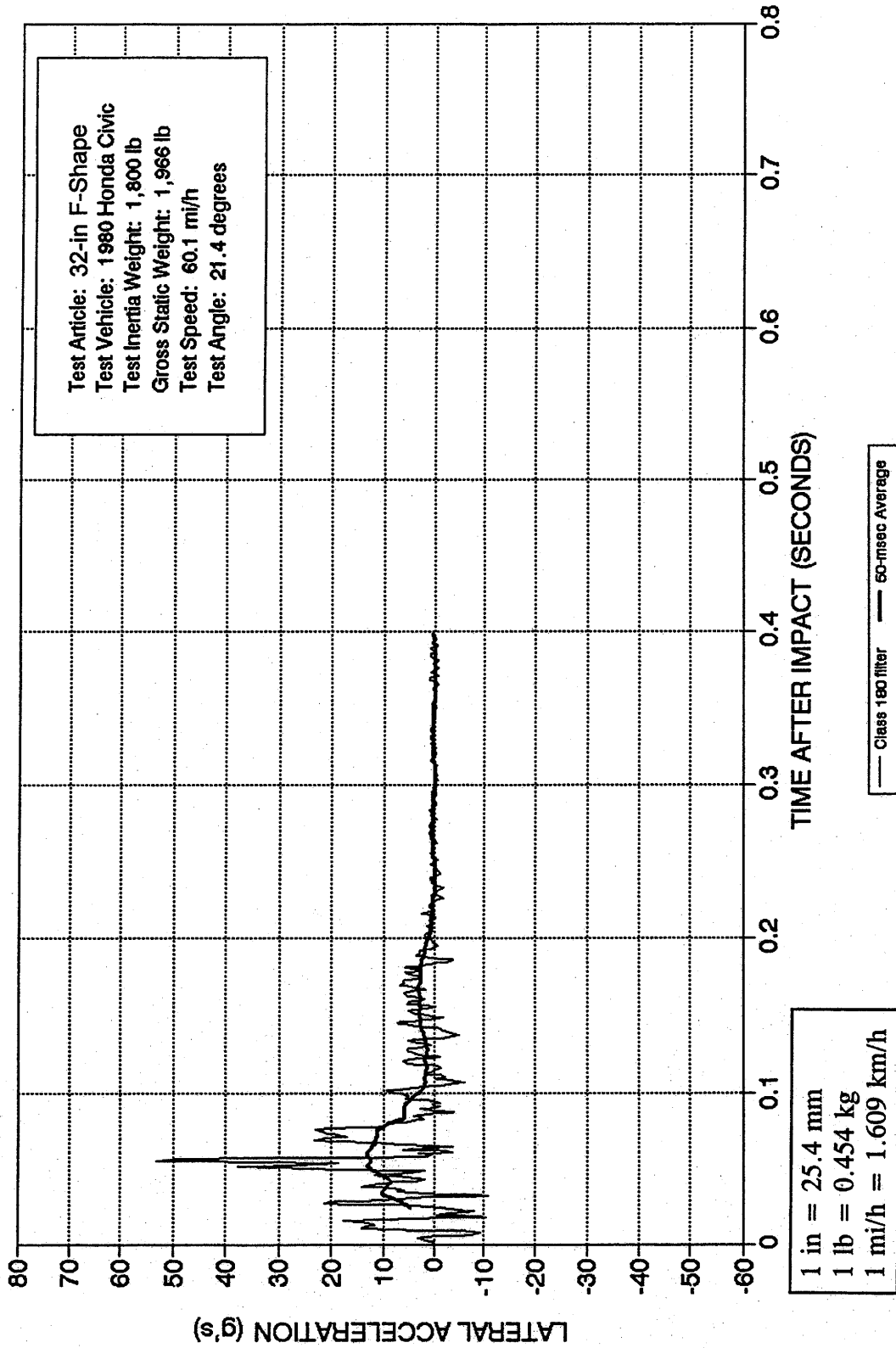
Figure 12. Vehicle lateral accelerometer trace for test 7069-3 (accelerometer located near center-of-gravity).
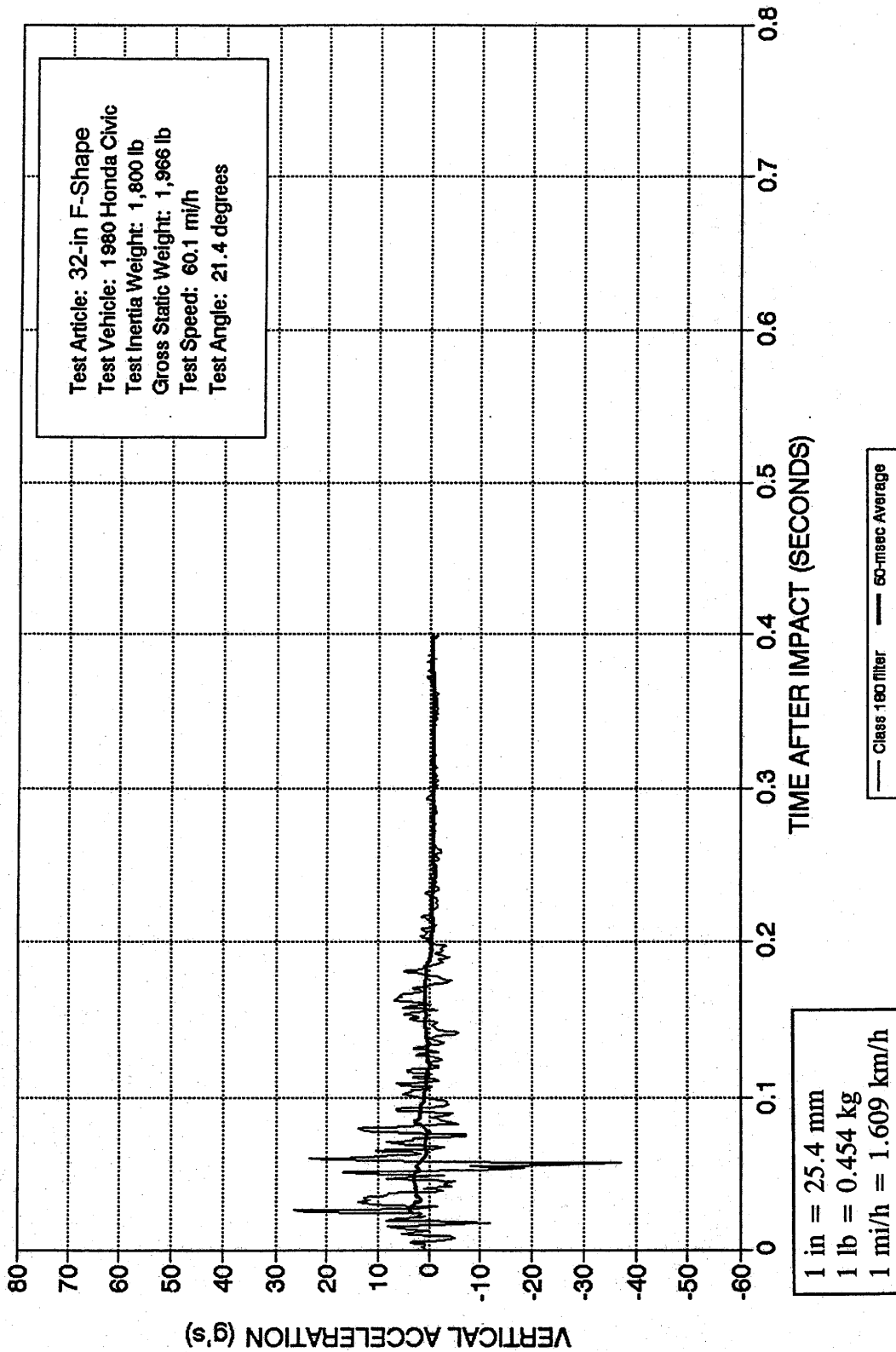
Figure 13. Vehicle vertical accelerometer trace for test 7069-3 (accelerometer located near center-of-gravity).

TEST 7069-4

Test Description

The 1981 Chevrolet pickup (figures 14 and 15) was directed into the bridge railing (figure 16) using a cable reverse tow and guidance system. Test inertia mass of the vehicle was 5,440 lb (2 470 kg) and its gross static mass was 5,780 lb (2 624 kg). The height to the lower edge of the vehicle bumper was 17.0 in (432 mm) and it was 26.25 in (667 mm) to the top of the bumper. Other dimensions and information on the test vehicle are given in figure 17. The vehicle was free-wheeling and unrestrained just prior to impact.

The speed of the vehicle at impact was 65.4 mi/h (105.2 km/h) and the angle of impact was 20.4 degrees. [The 1987 proposed test matrix required 65 mi/h (104.7 km/h), but the 1989 Guide Specification requires 60 mi/h (96.6 km/h).] The vehicle impacted the bridge railing at midlength. At approximately 0.013 s after impact the right front wheel began to ride up the face of the bridge railing, and at 0.019 s the right front tire aired out. The vehicle began to redirect as the rear end began to slide toward the bridge railing. The dummies began to move abruptly to the right at 0.046 s, and at 0.106 s the passenger head of the dummy shattered the right side window glass. At 0.139 s the left front wheel left the ground, and at 0.141 s the rear of the vehicle slapped the bridge railing and aired out the right rear tire. By 0.154 s the vehicle was totally airborne and remained so as it became parallel with the railing (at 0.179 s) and exited the railing (at 0.238 s). The left front wheel touched down at 0.287 s and the right touched down at 0.433 s. The vehicle exited the railing with a yaw angle of 0.4 degrees and a vehicle trajectory path of 7.4 degrees. The brakes were applied and the vehicle subsequently came to rest 240 ft (73 m) downstream and 37 ft (11 m) behind the point of impact.

As can be seen in figure 18, the railing received cosmetic damage and some scraping. There were tire marks on the face of the bridge railing which indicated the vehicle rose a maximum height of 24 in (610 mm) above the ground. The vehicle was in contact with the bridge railing for 18.0 ft (5.5 m).

The vehicle sustained extensive damage to the right side as shown in figure 19. Maximum crush at the right front corner at bumper height was 5.0 in (127 mm). The right front and right rear wheel rims were bent and the tires aired out. The wheel assembly and suspension was damaged. The passenger door was bent and jammed and the window broken out. The right rear panel was dented and scraped. The hood was bent and shifted to the left. The cab of the vehicle was twisted.

Test Results

Impact speed was 65.4 mi/h (105.2 km/h) and the angle of impact was 20.4 degrees. The exit speed at time of contact (0.238 s) was 56.9 mi/h (91.6 km/h) and the vehicle trajectory path was 7.3 degrees with a vehicle yaw angle of 0.4 degrees. The effective coefficient of friction was calculated to be 0.31. Occupant impact velocity was 12.5 ft/s (3.8 m/s) in the longitudinal direction and 24.1 ft/s (7.3 m/s) in the lateral direction. The highest

0.010-s occupant ridedown accelerations were -1.2 g (longitudinal) and 5.9 g (lateral). These data and other pertinent information from the test are summarized in figure 20 and table 3. Sequential photographs are shown in figures 21 and 22. Vehicular angular displacements are displayed in figure 23. Vehicular accelerations versus time traces filtered with SAE J211 filters are presented in figures 24 through 28. These data were further analyzed to obtain 0.050-s average accelerations versus time. A 0.050-s interval immediately prior to impact was averaged to establish zero acceleration. The data were then processed with a moving 0.050-s average window with the first 0.050-s average plotted at 0.026 s for each trace. The maximum 0.050-s averages were -4.7 g (longitudinal) and 13.1 g (lateral).

Conclusions

The 32-in (813-mm) F-shape bridge railing contained and smoothly redirected the vehicle with minimal lateral movement of the bridge railing. There were no debris or detached elements. There was no intrusion into the occupant compartment although some deformation of the right door occurred. The vehicle trajectory at loss of contact indicated minimum intrusion into adjacent traffic lanes. The vehicle remained upright and stable during the entire test period. See table 3 for a more detailed description.
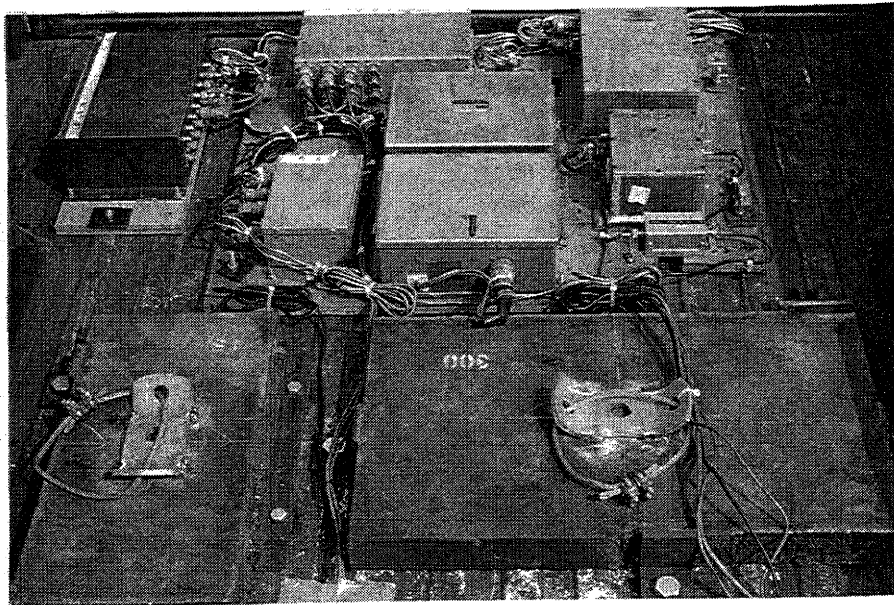
Figure 14.   Vehicle and instrumentation before test 7069-4.

Figure 15. Vehicle/bridge railing geometrics for test 7069-4.
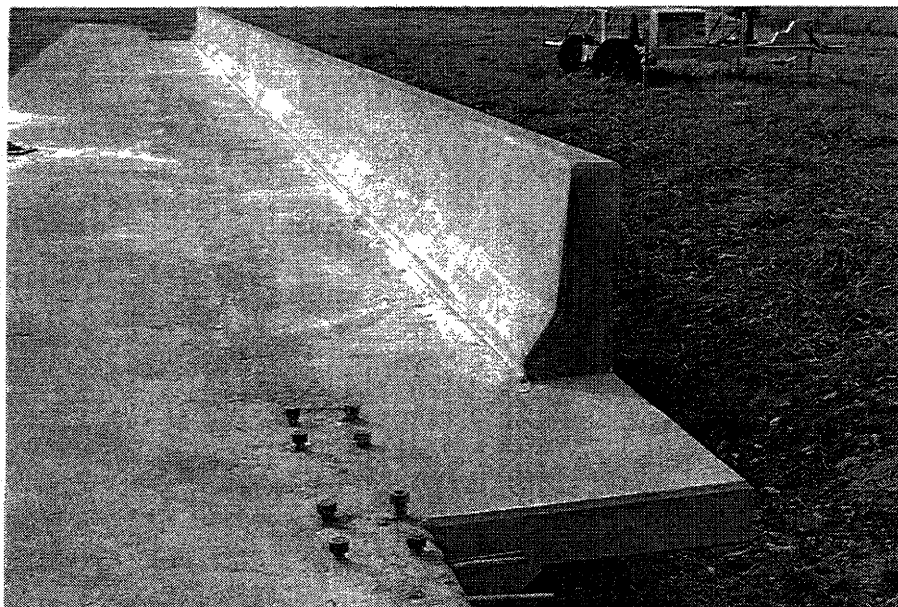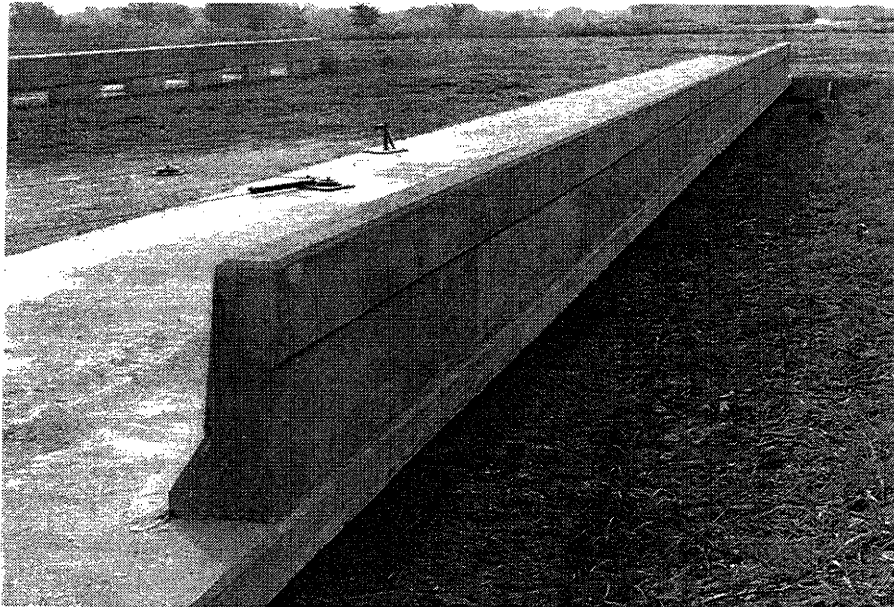
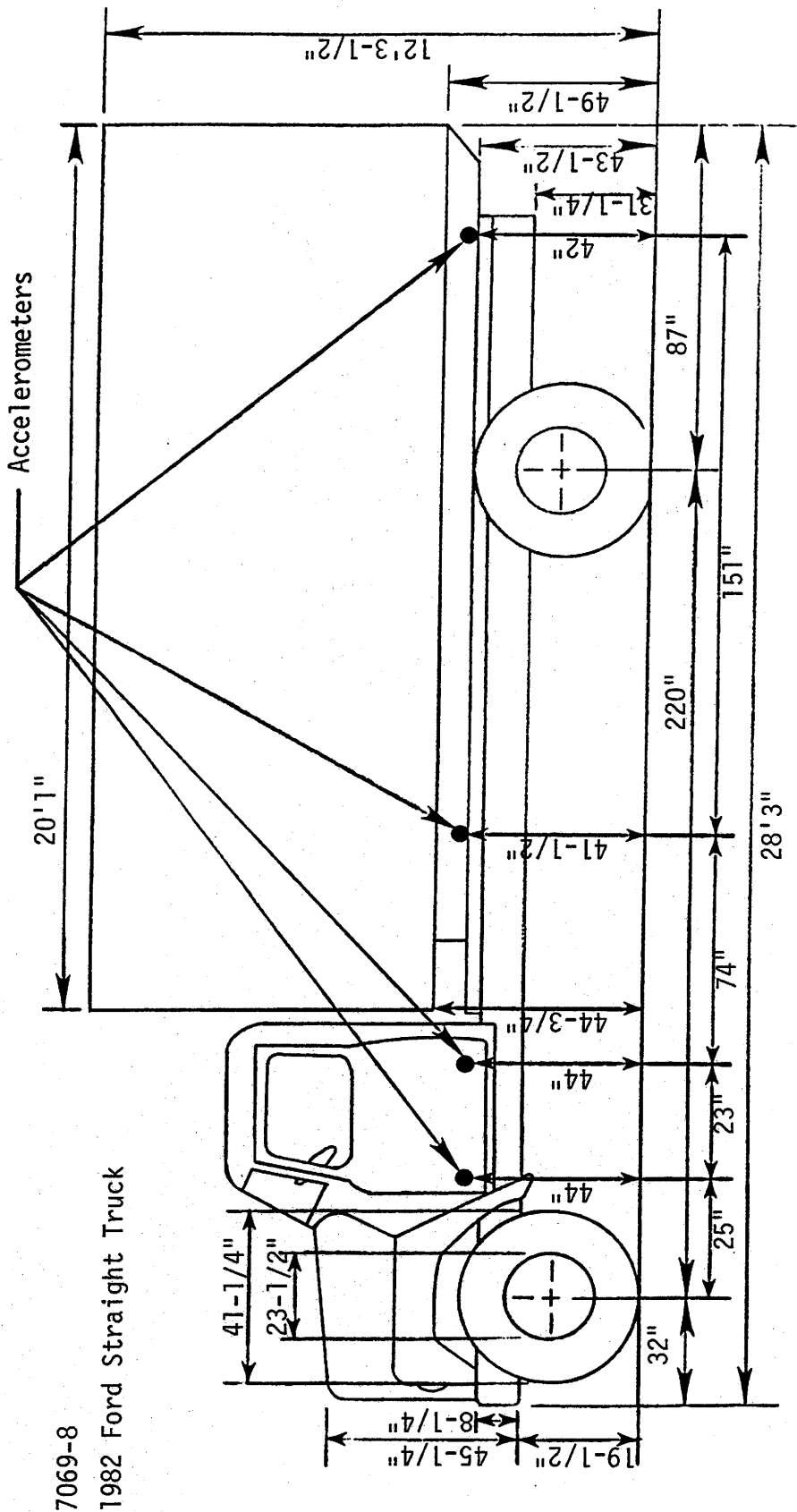Figure 16. 32-in (813-mm) F-shape bridge railing before test 7069-4.

Date: __7-30-87__   Test No.: __7069-4__   VIN: __1GCGC24M7BS180051__

Make: __Chevrolet__   Model: __Scottsdale__   Year: __1981__   Odometer: __112314__

Tire Size: __9.50R16.5__   Ply Rating: __4__   Bias Ply: __X__   Belted: ___   Radial: ___

Tire Condition: good __
                  fair __
           badly worn __
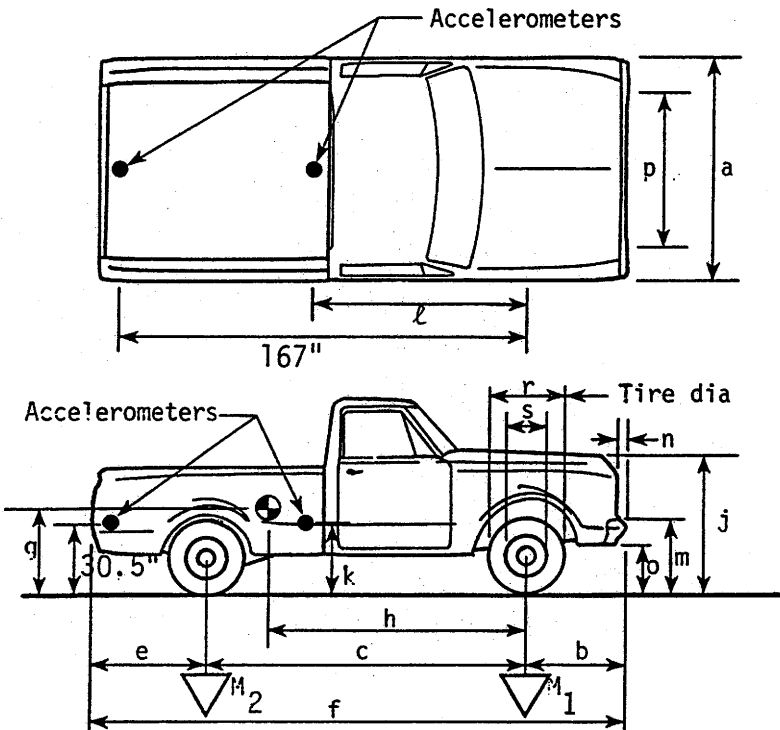
Vehicle Geometry - inches

a __70 1/4__   b __33 1/2__

c __132__   d*__71__

e __50 1/4__   f __215.75__

g __26.1__   h __66.7__

i __----__   j __44 1/4__

k __30 1/2__   ℓ __72 1/2__

m __26 1/4__   n __4__

o __17__   p __65 1/2__

r __29__   s __17__

Engine Type: __V8__

Engine CID: __350__

Transmission Type:
  Automatic or (Manual)
  FWD or (RWD) or 4WD

Body Type: __PU__

Steering Column Collapse
  Mechanism:
  __Behind wheel units
  __Convoluted tube
  __Cylindrical mesh units
  __Embedded ball
  __NOT collapsible
  __Other energy absorption
  __Unknown

Brakes:
  Front: disc __X__ drum ___
  Rear: disc ___ drum __X__

Accelerometers

167"

Accelerometers — Tire dia

30.5"

4-wheel weight
  for c.g. det.   ℓf __1340__   rf __1350__   ℓr __1400__   rr __1350__

Mass - pounds	Curb	Test Inertial	Gross Static
M_1	2667	2690	2890
M_2	2210	2750	2890
M_T	4877	5440	5780

Note any damage to vehicle prior to test:

_____

_____

*d = overall height of vehicle

1 in = 25.4 mm
1 lb = 0.454 kg

Figure 17.   Vehicle properties for test 7069-4.

Figure 18.   32-in (813-mm) F-shape bridge railing after test 7069-4.

Figure 19.   Vehicle after test 7069-4.

0.000 s	0.099 s
0.201 s	0.308 s

Test No. 7069-4
Date 7/30/87
Test Installation . . 32-in (813-mm) F-Shape
Bridge Railing
Installation Length . 100 ft (30 m)
Vehicle . . . . . . 1981 Chevrolet
Pickup
Vehicle Weight
Test Inertia . . . . 5,440 lb (2,470 kg)
Gross Static . . . . 5,780 lb (2,624 kg)
Vehicle Damage Classification
TAD 01RD4
CDC . . . . 01FREK2 & 01RYEW3
Maximum Vehicle Crush . 5.0 in (127 mm)

Impact Speed. . . . 65.4 mi/h (105.2 km/h)
Impact Angle. . . . 20.4 deg
Exit Speed. . . . . 56.9 mi/h (91.6 km/h)
Exit Trajectory . . 7.4 deg
Vehicle Accelerations
(Max. 0.050-sec Avg)
Longitudinal. . -4.7 g
Lateral . . . . 13.1 g
Occupant Impact Velocity
Longitudinal. . 12.5 ft/s (3.8 m/s)
Lateral . . . . 24.1 ft/s (7.3 m/s)
Occupant Ridedown Accelerations
Longitudinal. . -1.2 g
Lateral . . . . 5.9 g

32 in

7 in

3 in

(1 in = 25.4 mm)

Figure 20. Summary of results for test 7069-4.

33

Table 3. Evaluation of crash test no. 7069-4.
{32-in (81 cm) F-Shape Bridge Railing [5,440 lb (2 470 kg)|65.4 mi/h (105.2 km/h)|20.4 degrees]}

CRITERIA	TEST RESULTS	PASS/FAIL*
A. Must contain vehicle	Vehicle was contained	Pass
B. Debris shall not penetrate passenger compartment	No debris penetrated passenger compartment	Pass
C. Passenger compartment must have essentially no deformation	Minimal deformation	Pass
D. Vehicle must remain upright	Vehicle did remained upright	Pass
E. Must smoothly redirect the vehicle	Vehicle was smoothly redirected	Pass
F. Effective coefficient of friction μ — Assessment 0 - .25 — Good .26 - .35 — Fair > .35 — Marginal	μ — Assessment .31 — Good	Pass
G. Shall be less than Occupant Impact Velocity - ft/s (m/s) Longitudinal — Lateral 30 (9.2) — 25 (7.6) Occupant Ridedown Accelerations - g's Longitudinal — Lateral 15 — 15	Occupant Impact Velocity - ft/s (m/s) Longitudinal — Lateral 12.5 (3.8) — 24.1 (7.3) Occupant Ridedown Accelerations - g's Longitudinal — Lateral -1.2 — 5.9	Pass
H. Exit angle shall be less than 12 degrees	Exit angle was 7.3 degrees	Pass

* A, B, C, and D are required. E, F, G, and H are desired. (See table 2)

0.000 s

0.051 s
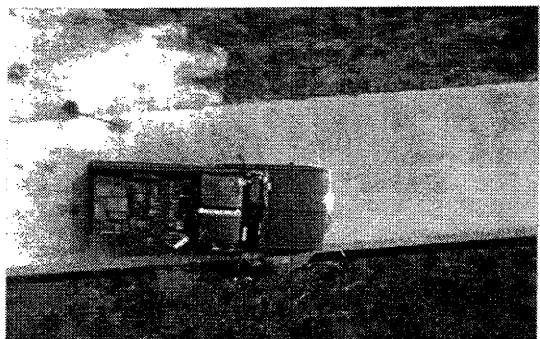
0.099 s
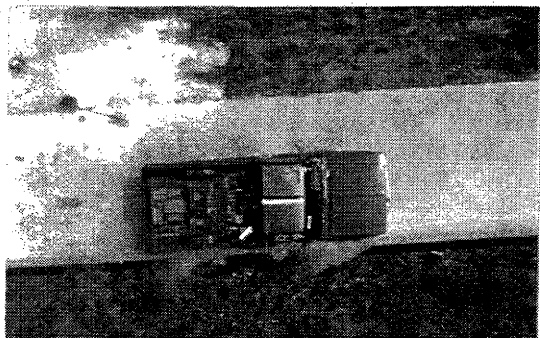
0.150 s

Figure 21.   Sequential photographs for test 7069-4.
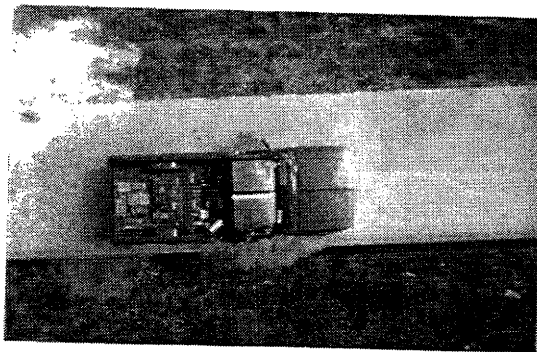
0.201 s
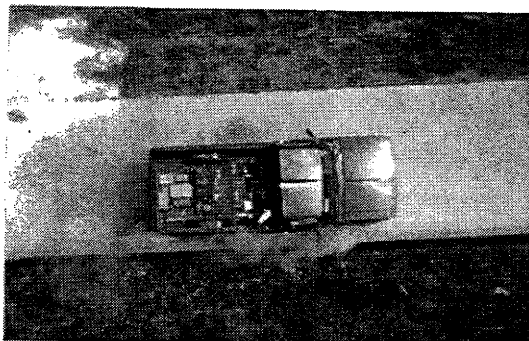
0.250 s
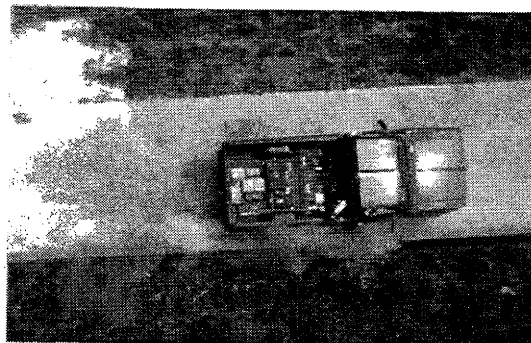
0.308 s
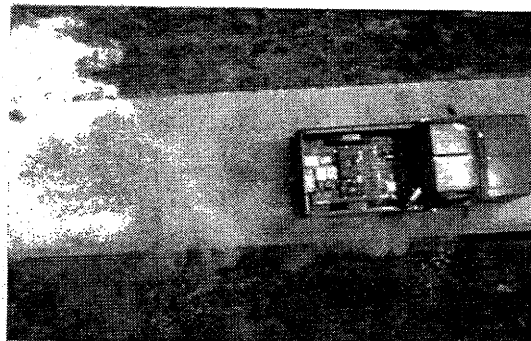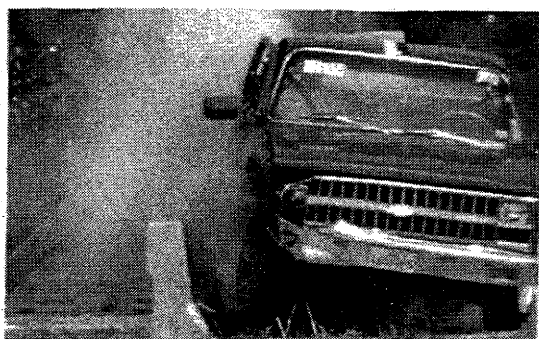
0.376 s

Figure 21. Sequential photographs for test 7069-4 (continued).
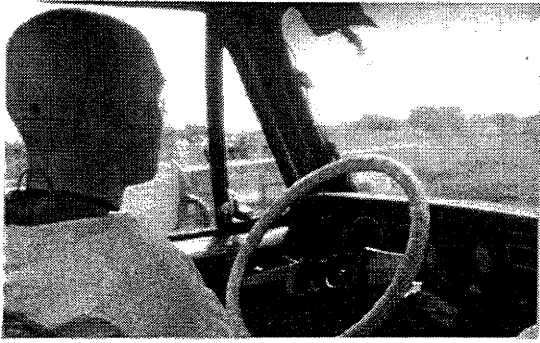
0.000 s

0.197 s

0.046 s
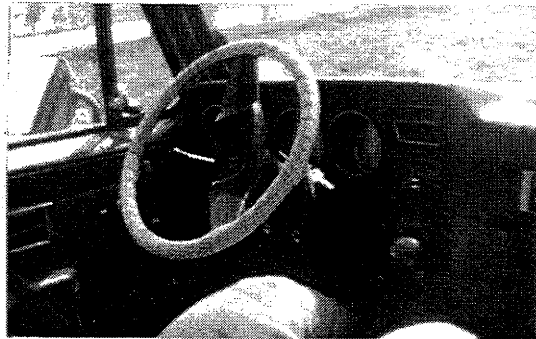
0.255 s
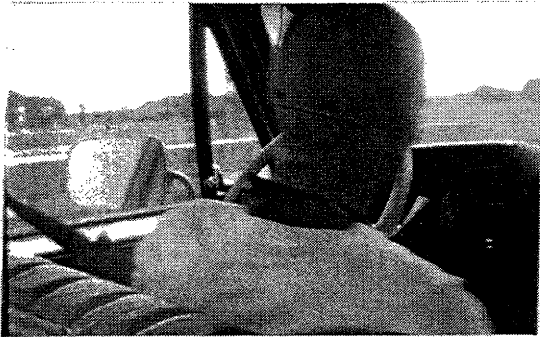
0.104 s
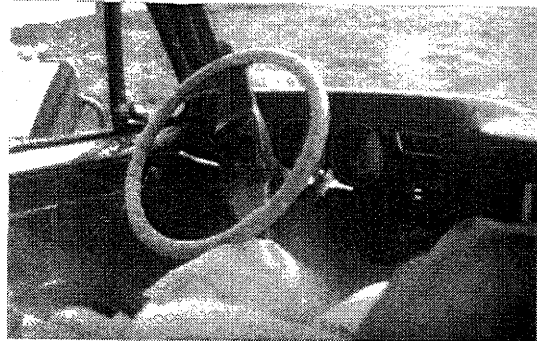
0.313 s

0.151 s

0.371 s

Figure 22. Interior sequential photographs for test 7069-4.
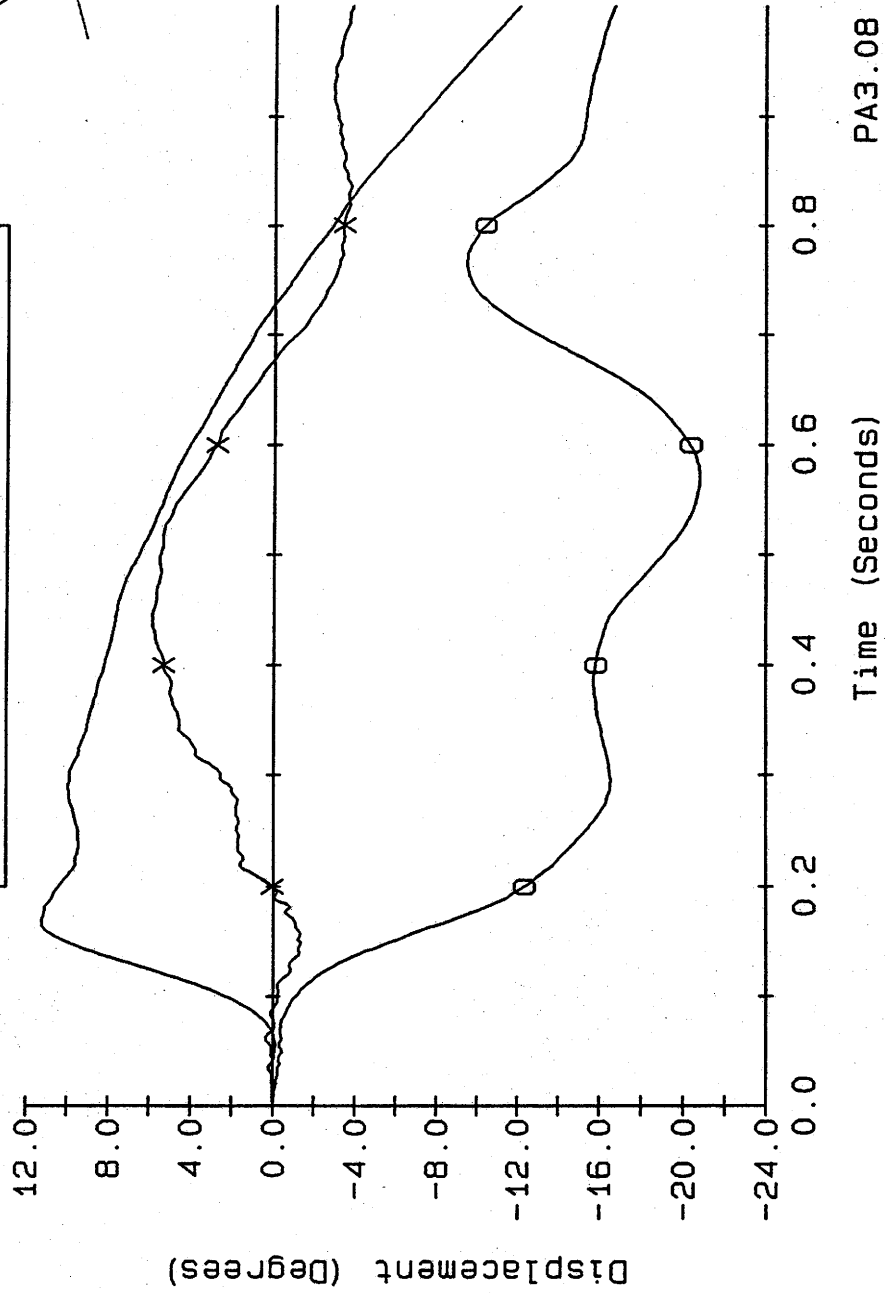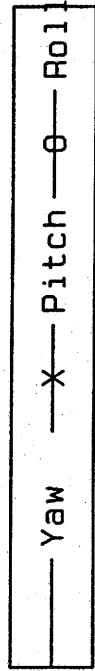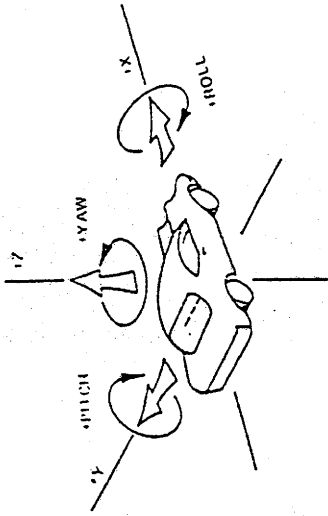
Figure 23. Vehicle angular displacements for test 7069-4.

38
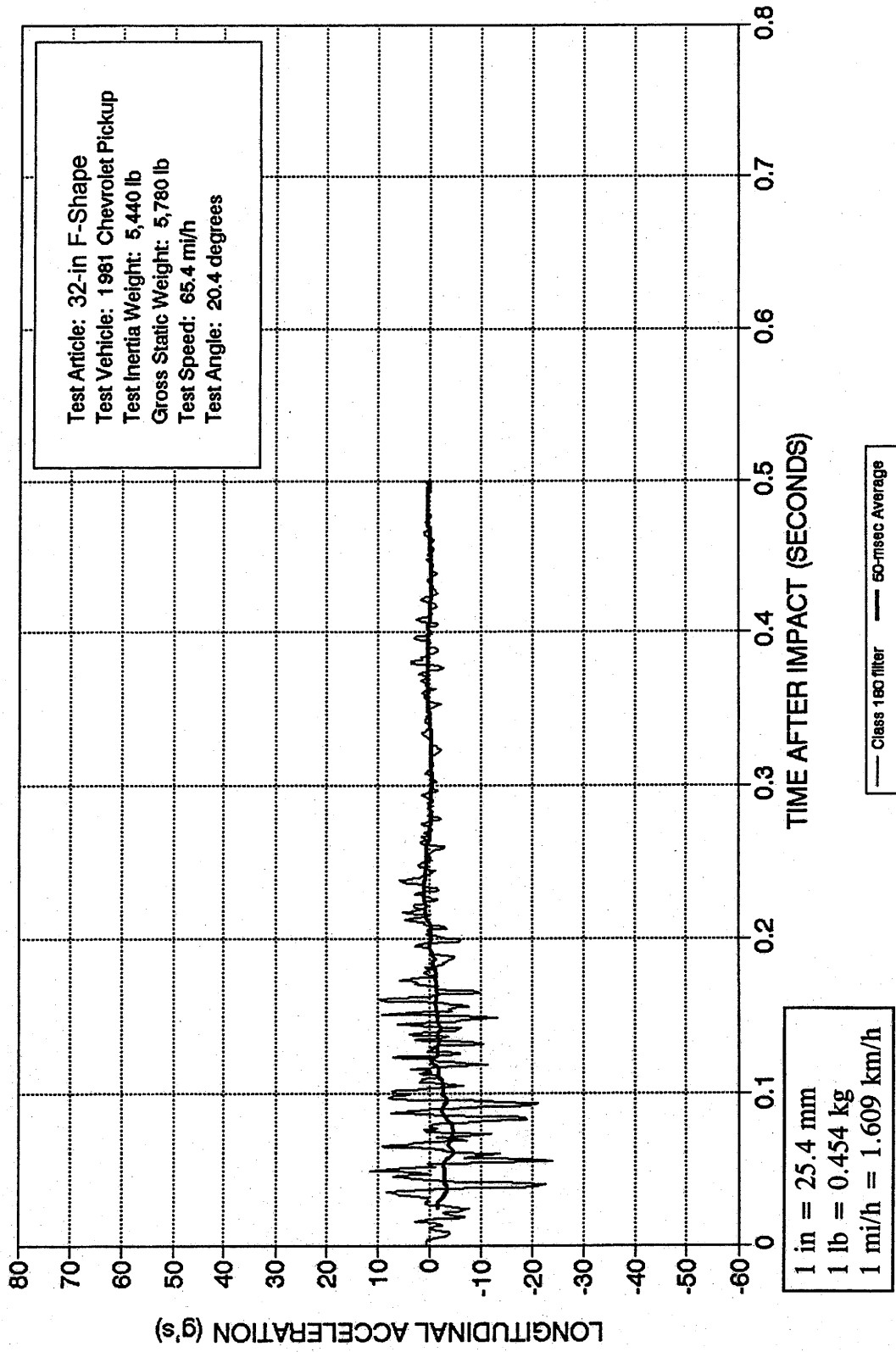
Figure 24. Vehicle longitudinal accelerometer trace for test 7069-4
(accelerometer located at center-of-gravity).
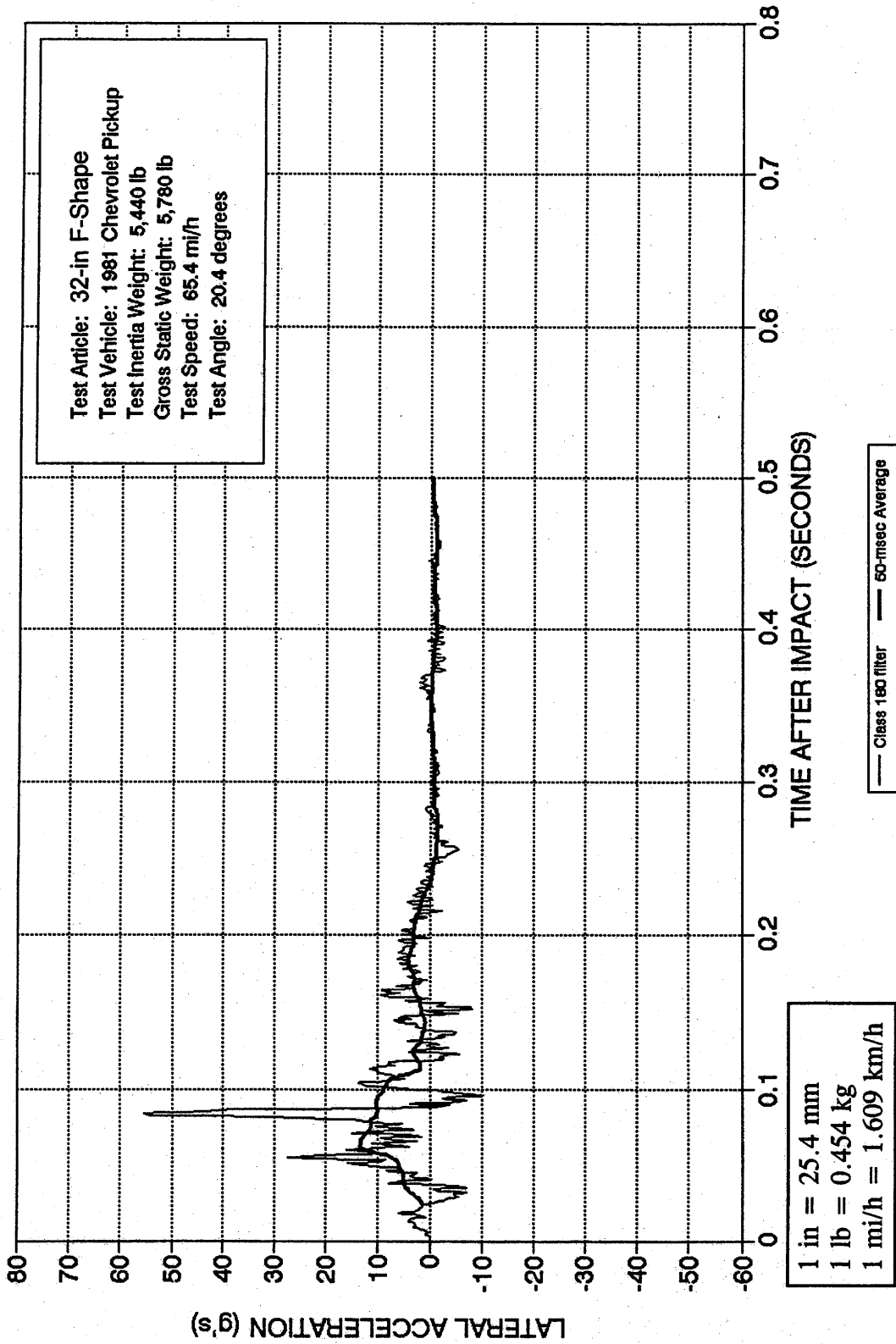
Figure 25. Vehicle lateral accelerometer trace for test 7069-4 (accelerometer located at center-of-gravity).

CRASH TEST 7069-4

Accelerometer near center-of-gravity

Test Article: 32-in F-Shape
Test Vehicle: 1981 Chevrolet Pickup
Test Inertia Weight: 5,440 lb
Gross Static Weight: 5,780 lb
Test Speed: 65.4 mi/h
Test Angle: 20.4 degrees

1 in = 25.4 mm
1 lb = 0.454 kg
1 mi/h = 1.609 km/h

Class 180 filter   50-msec Average

TIME AFTER IMPACT (SECONDS)

VERTICAL ACCELERATION (g's)
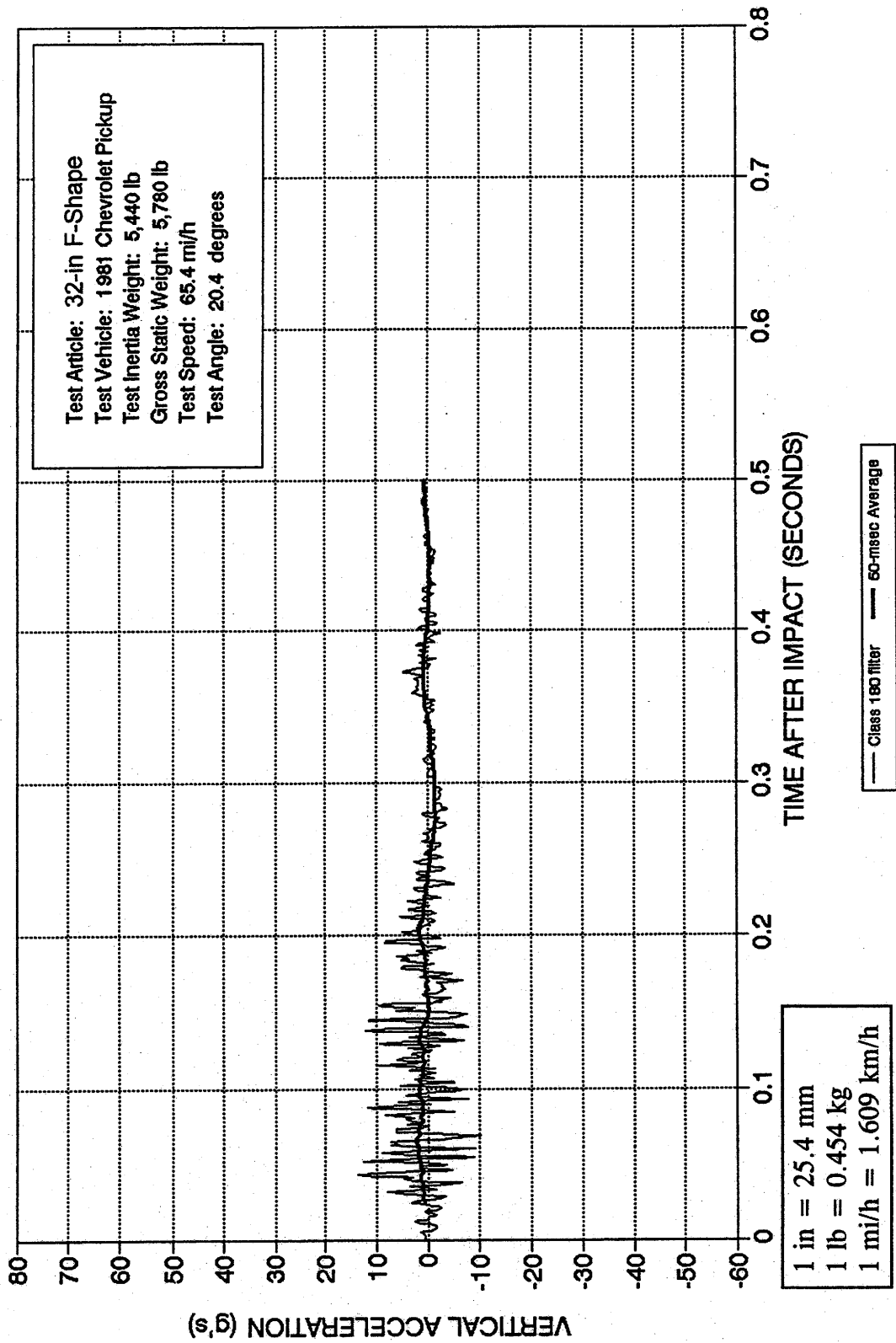
Figure 26. Vehicle vertical accelerometer trace for test 7069-4
(accelerometer located at center-of-gravity).

CRASH TEST 7069-4
Accelerometer at rear of vehicle

Test Article: 32-in F-Shape
Test Vehicle: 1981 Chevrolet Pickup
Test Inertia Weight: 5,440 lb
Gross Static Weight: 5,780 lb
Test Speed: 65.4 mi/h
Test Angle: 20.4 degrees

LONGITUDINAL ACCELERATION (g's)

TIME AFTER IMPACT (SECONDS)

1 in = 25.4 mm
1 lb = 0.454 kg
1 mi/h = 1.609 km/h

Class 180 filter   50-msec Average
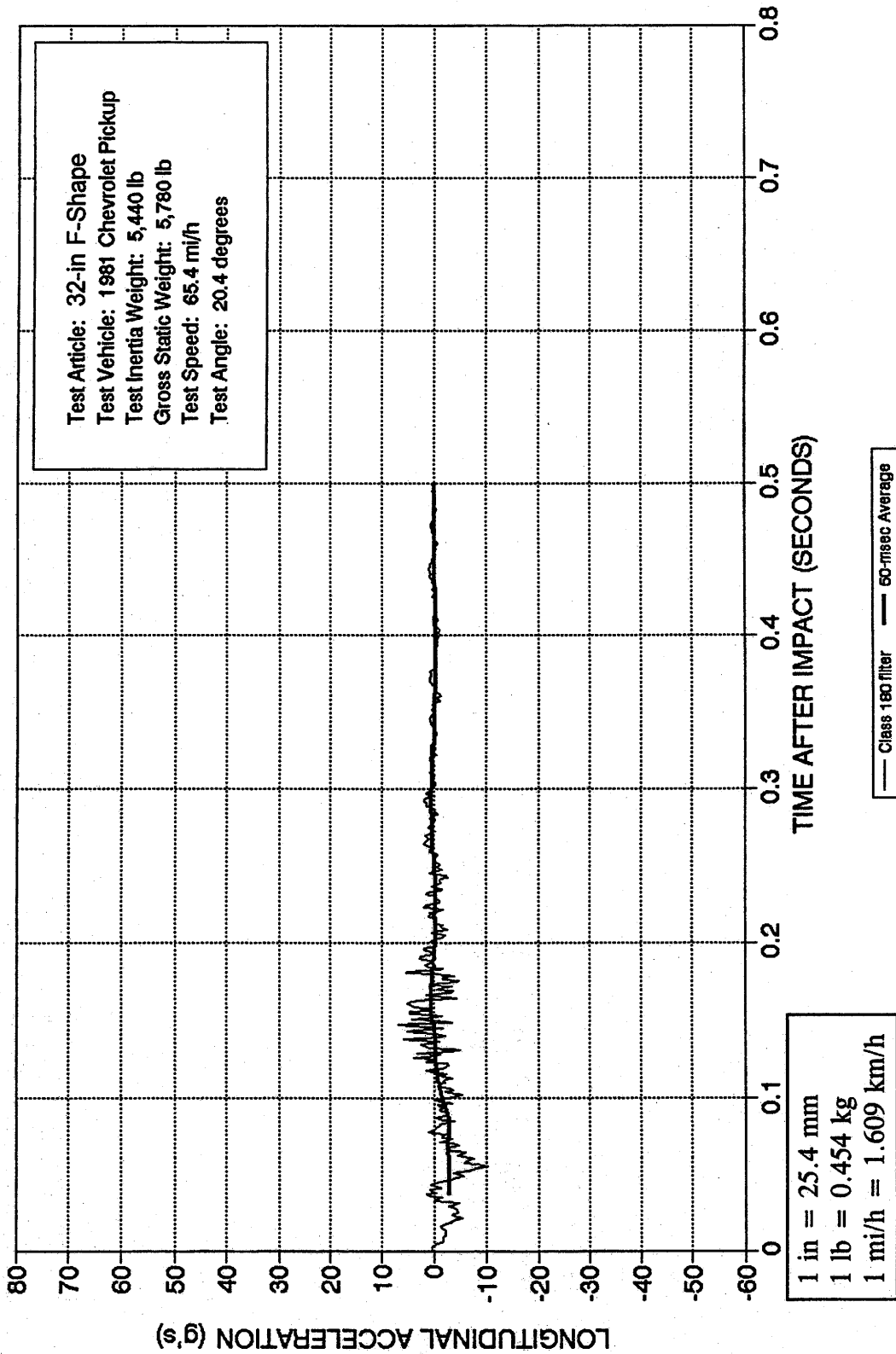
Figure 27.   Vehicle longitudinal accelerometer trace for test 7069-4 (accelerometer located at rear of vehicle).

CRASH TEST 7069-4
Accelerometer at rear of vehicle

Test Article: 32-in F-Shape
Test Vehicle: 1981 Chevrolet Pickup
Test Inertia Weight: 5,440 lb
Gross Static Weight: 5,780 lb
Test Speed: 65.4 mi/h
Test Angle: 20.4 degrees

1 in = 25.4 mm
1 lb = 0.454 kg
1 mi/h = 1.609 km/h

— Class 180 filter   — 50-msec Average
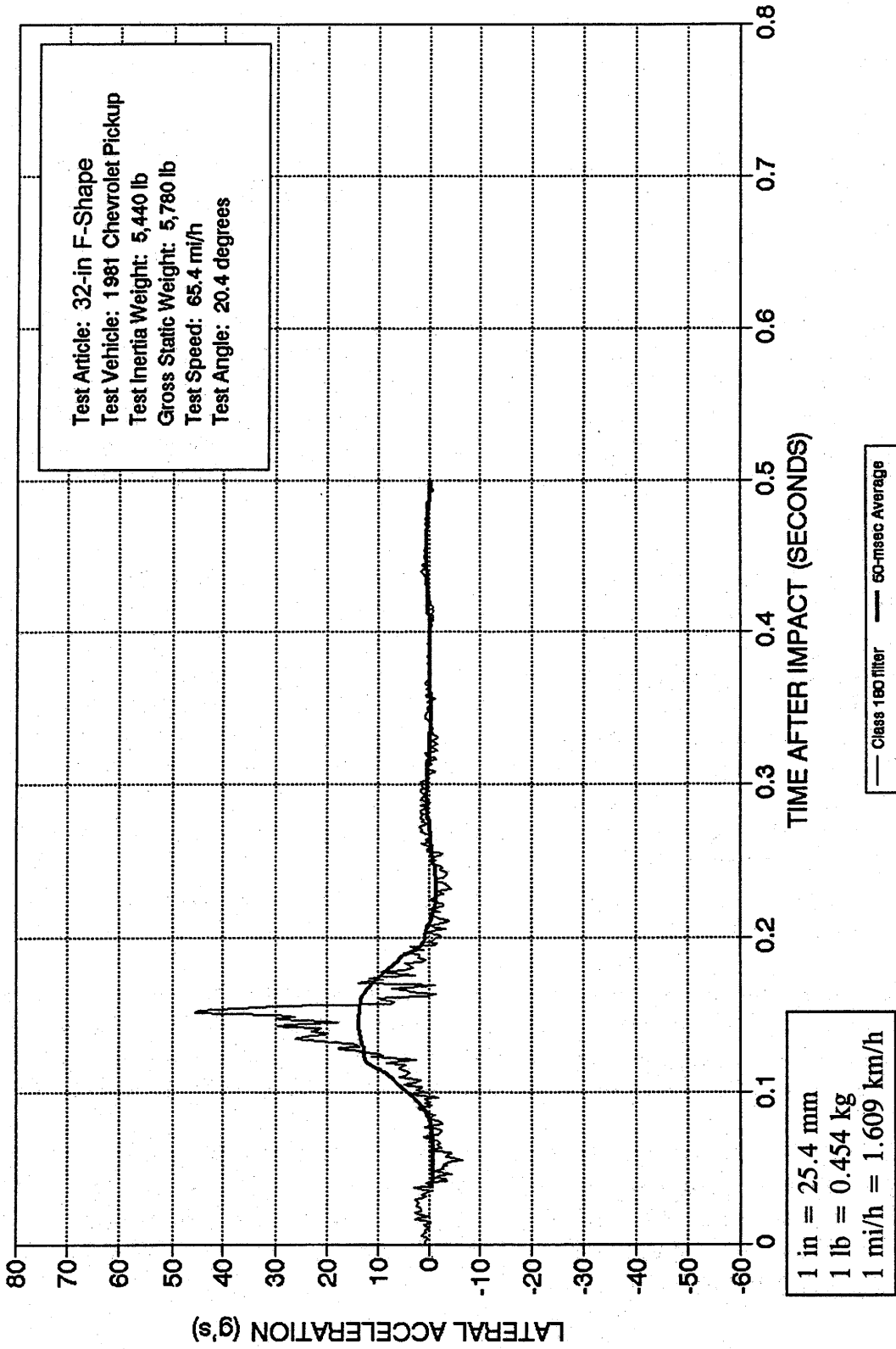
Figure 28. Vehicle lateral accelerometer trace for test 7069-4 (accelerometer located at rear of vehicle).

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TEST 7069-8

NOTE: In test 7069-8, the engine of the test vehicle (which was remotely controlled) stalled, causing the impact speed of the test vehicle to be lower than specified in the crash test requirements [46.7 mi/h (75.2 km/h) vs. 50 mi/h (80.5 km/h)]. The test was repeated (7069-9) and again the impact speed was too low [47.3 mi/h (76.2 km/h) vs. 50 mi/h (80.5 km/h)]. In a third test (7069-11), an impact speed of 52.1 mi/h (132.3 km/h) was attained. Descriptions for all three of these tests are included in this report.

Test Description

The 1982 Ford single-unit truck (figures 29 and 30) was directed into the 32-in (813-mm) F-shape bridge railing (figure 31) using a remote control guidance system. Empty weight of the vehicle was 13,850 lb (6 288 kg) and its test inertia weight was 18,050 lb (8 195 kg). The height to the lower edge of the vehicle bumper was 19.5 in (495 mm) and it was 27.75 in (705 mm) to the top of the bumper. Other dimensions and information on the test vehicle are given in figure 32. The vehicle was free-wheeling and unrestrained just prior to impact.

The speed of the vehicle at impact was 46.7 mi/h (75.1 km/h) and the angle of impact was 15.0 degrees. The vehicle impacted the bridge railing at midlength. At approximately 0.021 s after impact the right front wheel began to ride up the face of the bridge railing, and at 0.163 s the left front tire began to leave the ground. The vehicle began to redirect at 0.184 s as the rear end began to slide toward the bridge railing. At 0.343 s the left rear wheels left the ground, and at approximately 0.448 s the rear of the vehicle slapped the bridge railing. By approximately 0.495 s the vehicle became parallel with the railing and was continuing to roll to the right. As the vehicle continued along the railing the lower edge of the bed rode along the top of the railing. A maximum roll angle of 34 degrees was achieved at about 1.286 s. The vehicle slid off the end of the bridge railing at about 1.713 s after impact. The brakes were applied and the vehicle subsequently came to rest 186 ft (57 m) downstream.

As can be seen in figure 33, the railing received cosmetic damage and some scraping. There were tire marks on the face of the bridge railing and along the top. The top of the bridge railing was scraped along the remaining length from the lower edge of the bed of the truck (see figure 34). The vehicle was in contact with the bridge railing for 60 ft (18 m).

The vehicle sustained extensive damage to the right side as shown in figure 35. Maximum crush at the right front corner at bumper height was 6.0 in (152 mm). The right front wheel rim was bent and the tire damaged. The spring and spring shackle were broken loose from the axle. The steering gear box and steering cylinder were damaged. Also, the fuel tank broke loose from the truck.

Test Results

Impact speed was 46.7 mi/h (75.1 km/h) and the angle of impact was 15.0 degrees. The exit speed was not attainable. The effective coefficient of friction was calculated to be 0.76. The occupant impact velocity was 11.9 ft/s (3.6 m/s) in the longitudinal direction and 9.2 ft/s (2.8 m/s) in the lateral direction. The highest 0.010-s occupant ridedown accelerations were -3.8 g (longitudinal) and 6.1 g (lateral). These data and other pertinent information from the test are summarized in figure 36 and table 4. Sequential photographs are shown in figures 37 and 38. Vehicular angular displacements are displayed in figure 39.

Vehicular accelerations versus time traces filtered with SAE J211 filters are presented in figures 40 through 44. These data were further analyzed to obtain 0.050-s average accelerations versus time. A 0.050-s interval immediately prior to impact was averaged to establish zero acceleration. The data were then processed with a moving 0.050-s average window with the first 0.050-s average plotted at 0.026-s for each trace. The maximum 0.050-s averages were -2.2 g (longitudinal) and 3.4 g (lateral).

Conclusions

The 32-in (813-mm) F-shape bridge railing contained and smoothly redirected the vehicle with no lateral movement of the bridge railing. There were no debris or detached elements. There was no intrusion into the occupant compartment. The vehicle trajectory at loss of contact indicated minimum intrusion into adjacent traffic lanes. The vehicle remained upright and marginally stable during the entire test period. See table 4 for a more detailed description.
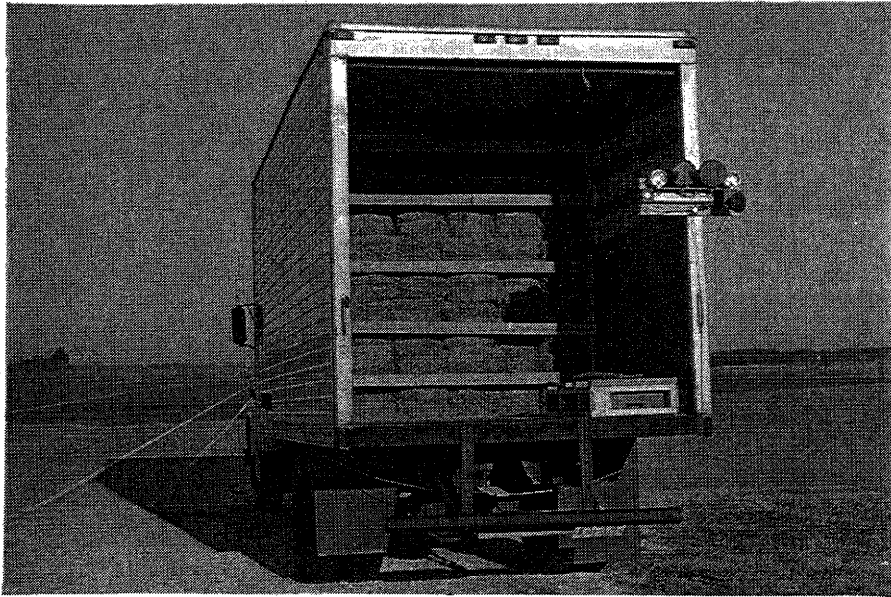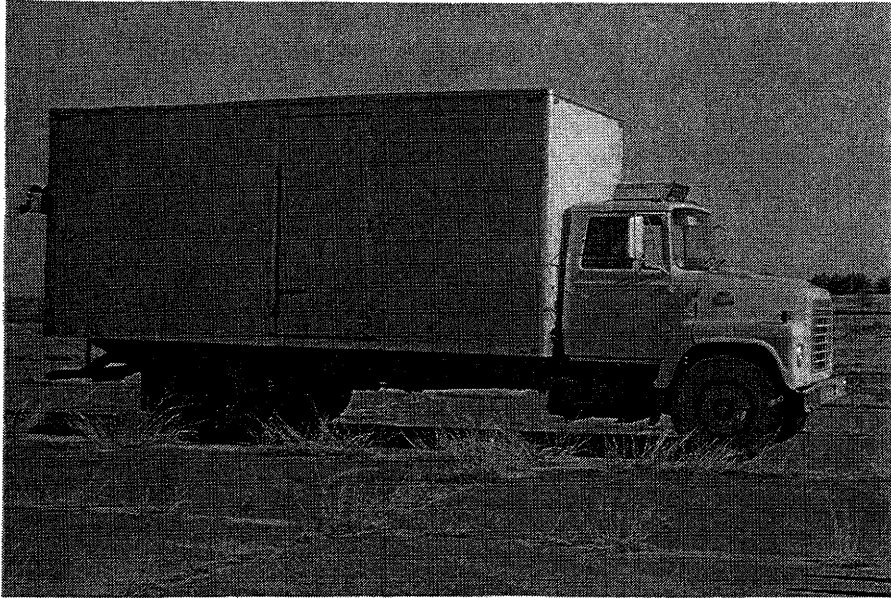
Figure 29.   Vehicle before test 7069-8.
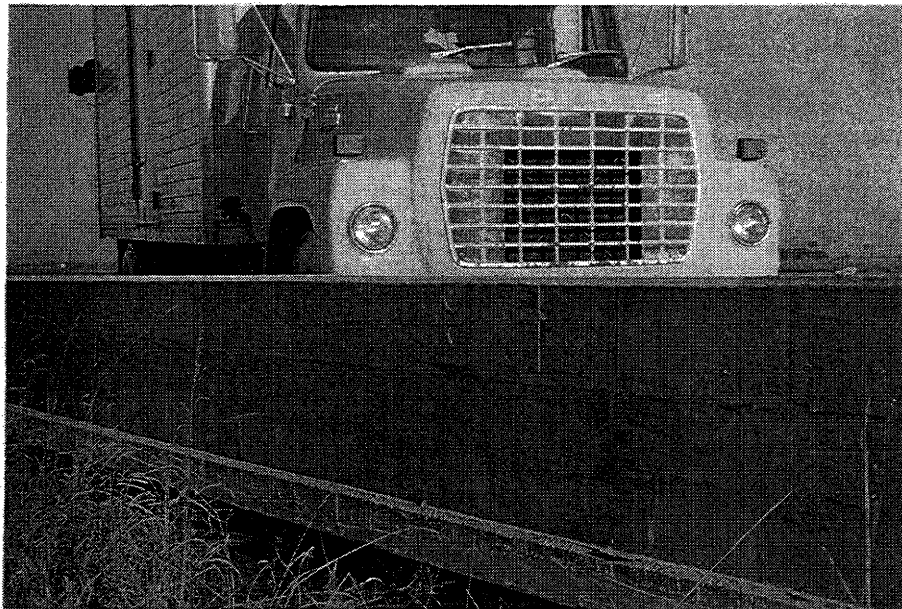
Figure 30.   Vehicle/bridge railing geometrics for test 7069-8.
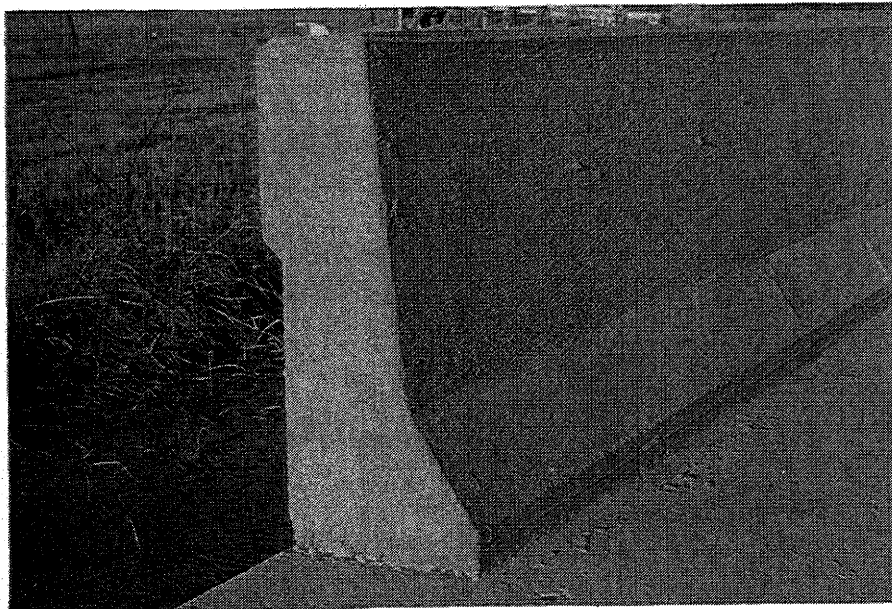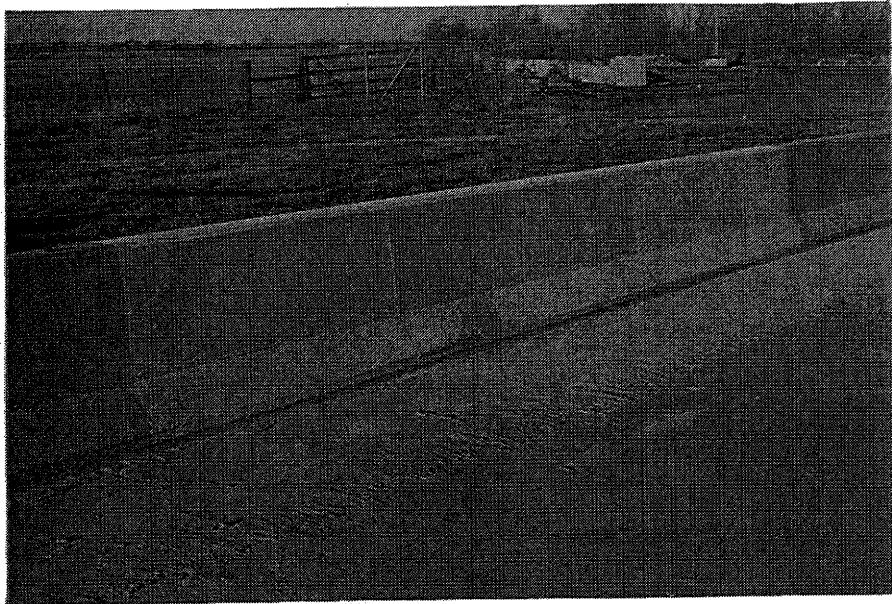
Figure 31. 32-in (813-mm) F-shape bridge railing before test 7069-8.

7069-8
1982 Ford Straight Truck

Accelerometers

20'1"

12'3-1/2"

49-1/2"

43-1/2"

31-1/4"

42"

87"

220"

151"

41-1/2"

28'3"

44-3/4"

74"

44"

23"

25"

44"

32"

41-1/4"

23-1/2"

8-1/4"

45-1/4"

19-1/2"

EMPTY WEIGHTS

Weight on Front Axle : LF 3,420   RF 3,630
Weight on Rear Axle : LR 3,520   RR 3,280

TOTAL EMPTY WEIGHT :   13,850

LOADED WEIGHTS

Weight on Front Axle : LF 3,900   RF 4,050
Weight on Rear Axle : RF 5,100   RR 4,800

TOTAL LOADED WEIGHT :   17,850
                            + 200 lbs added   just prior
                              18,050   to testing

1 in = 25.4 mm

Figure 32. Vehicle properties for test 7069-8.

49
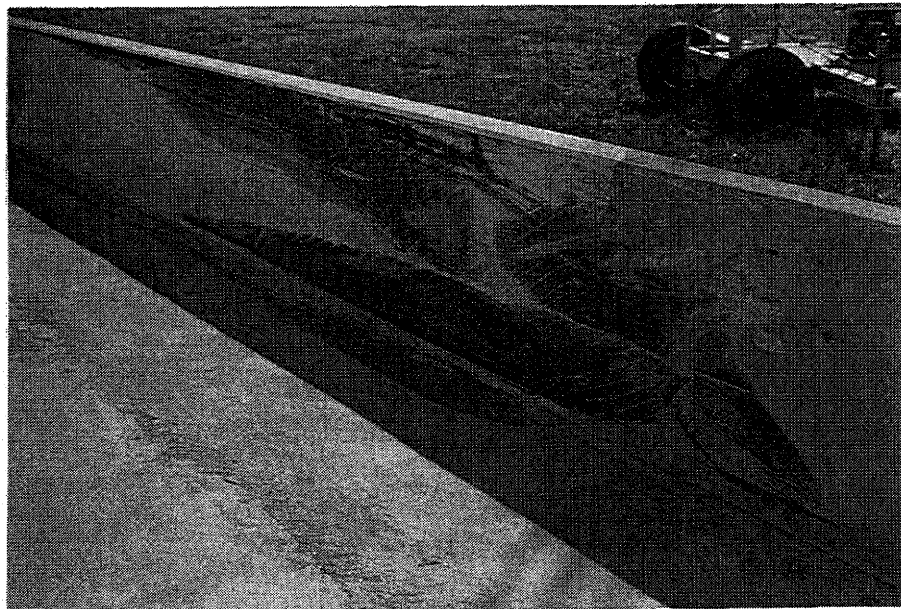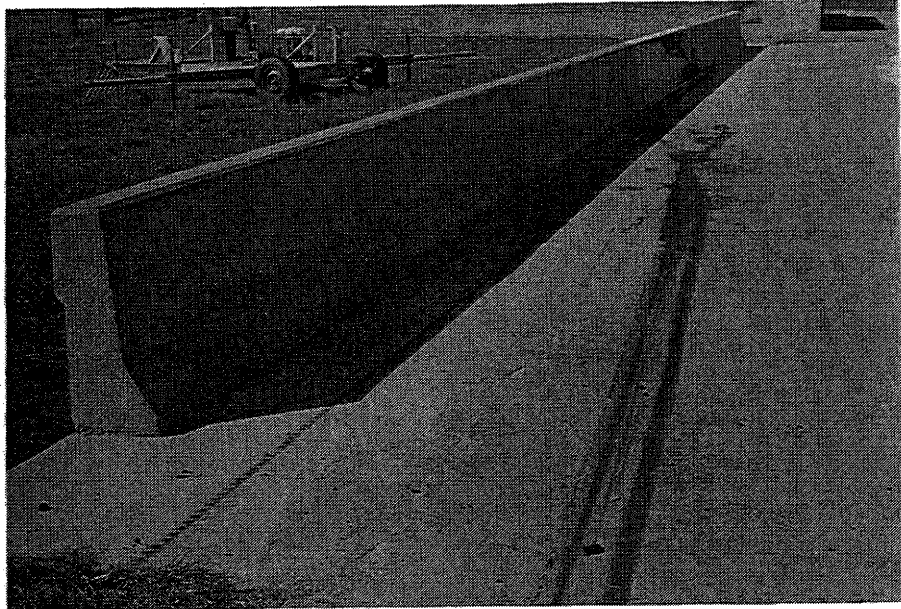
Figure 33. 32-in (813-mm) F-shape bridge railing after test 7069-8.
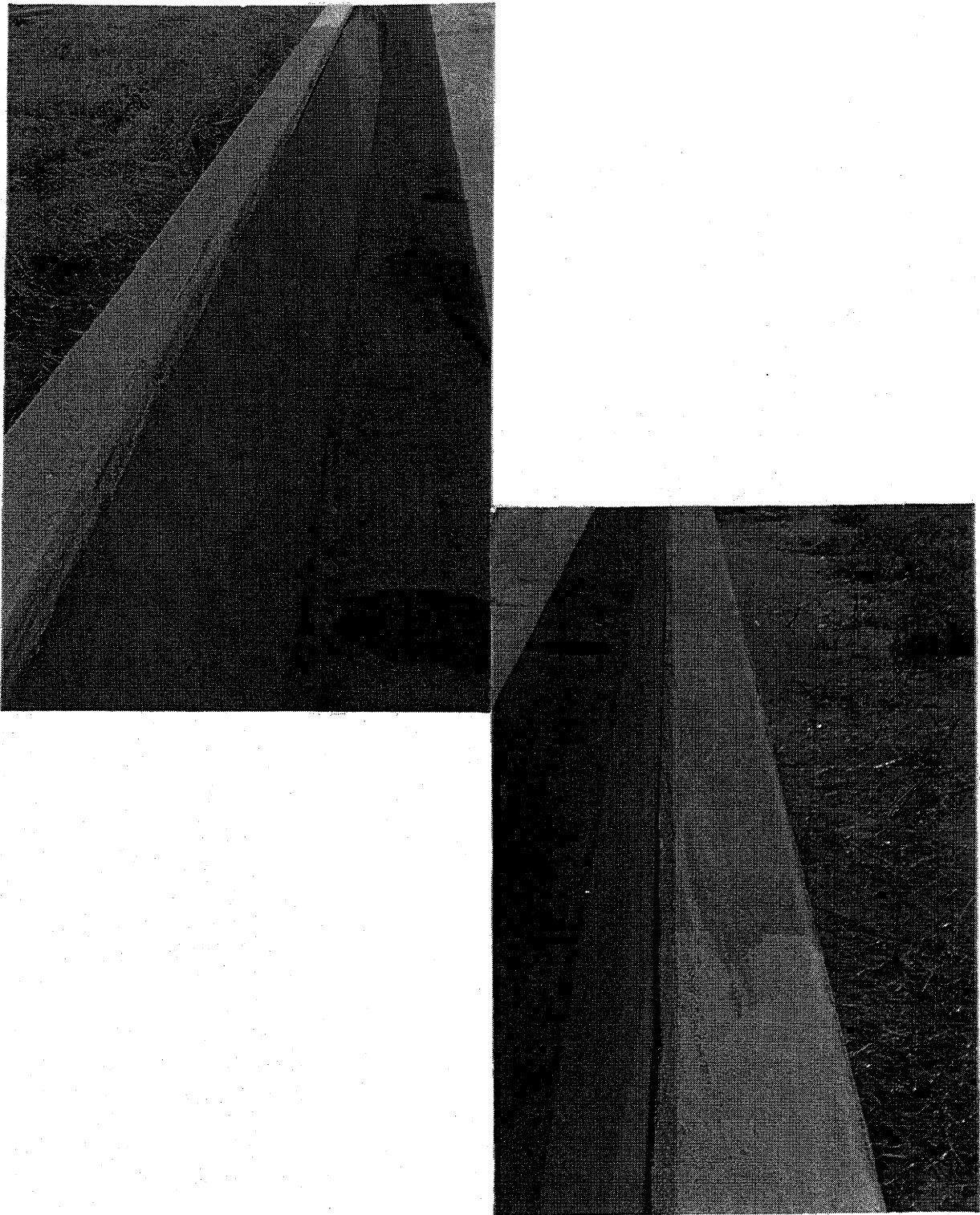
Figure 34. Damage to top of bridge railing caused by lower edge of bed of vehicle.

51
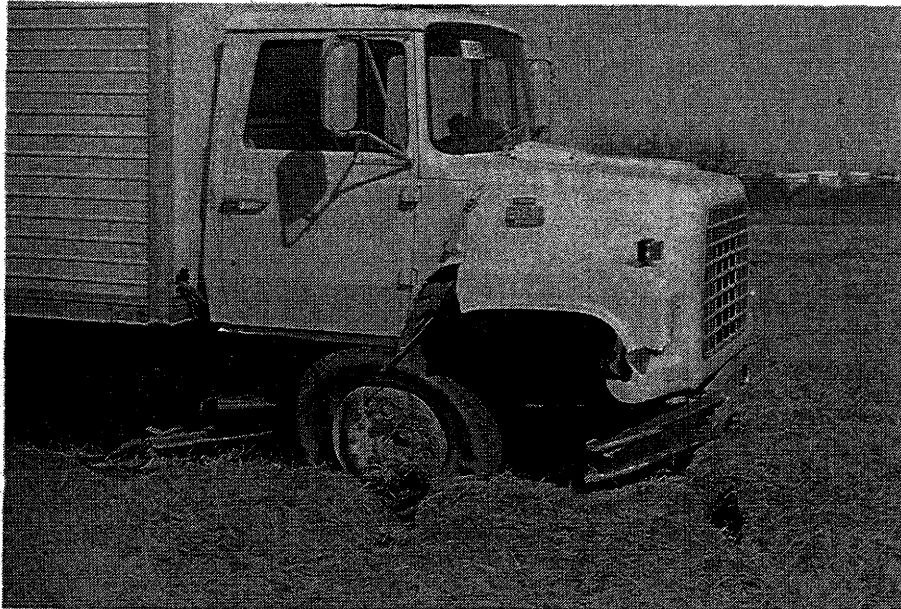
Figure 35.   Vehicle after test 7069-8.

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Test No.	. .	7069-8
Date	. .	1/28/88
Test Installation . .	. .	32-in (813-mm) F-Shape Bridge Railing
Installation Length .	. .	100 ft (30 m)
Vehicle	. .	1982 Ford Single-Unit Truck
Vehicle Weight		
Empty Weight	. .	13,050 lb (6,288 kg)
Test Inertia	. .	18,050 lb (8,195 kg)
Maximum Vehicle Crush	. .	6.0 in (152 mm)

Impact Speed. . . .	. .	46.7 mi/h (75.1 km/h)
Impact Angle. . . .	. .	15.0 deg
Exit Speed	. .	N/A
Exit Trajectory . .	. .	5.0 deg
Vehicle Accelerations		
(Max. 0.050-sec Avg)		
Longitudinal. . .	. .	-2.2 g
Lateral	. .	3.4 g
Occupant Impact Velocity		
Longitudinal. . .	. .	11.8 ft/s (3.6 m/s)
Lateral	. .	9.2 ft/s (2.8 m/s)
Occupant Ridedown Accelerations		
Longitudinal. . .	. .	-3.8 g
Lateral	. .	6.1 g

Figure 36. Summary of results for test 7069-8.

32 in

7 in   3 in

(1 in = 25.4 mm)

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Table 4. Evaluation of crash test no. 7069-8.
{32-in (81 cm) F-shape Bridge Rail [18,050 lb (8 195 kg)|46.7 mi/h (75.1 km/h)|15.0 degrees]}

	CRITERIA	TEST RESULTS	PASS/FAIL*
A.	Must contain vehicle	Vehicle was contained	Pass
B.	Debris shall not penetrate passenger compartment	No debris penetrated passenger compartment	Pass
C.	Passenger compartment must have essentially no deformation	Acceptable deformation	Pass
D.	Vehicle must remain upright	Vehicle remained upright	Pass
E.	Must smoothly redirect the vehicle	Vehicle was smoothly redirected	Pass
F.	Effective coefficient of friction μ Assessment 0 - .25 Good .26 - .35 Fair > .35 Marginal	μ Assessment .76 Pass	
G.	Shall be less than Occupant Impact Velocity - ft/s (m/s) Longitudinal Lateral 30 (9.2) 25 (7.6) Occupant Ridedown Accelerations - g's Longitudinal Lateral 15 15	Not applicable because not redirected into traffic. Occupant Impact Velocity - ft/s (m/s) Longitudinal Lateral 11.8 (3.6) 9.2 (2.8) Occupant Ridedown Accelerations - g's Longitudinal Lateral -3.8 6.1	N/A N/A
H.	Exit angle shall be less than 12 degrees	about 5 degrees	

* A, B, C, and D are required. E, F, and H are desired. G is not applicable for this test. (See table 5)

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Table 2. Bridge railing performance levels and crash test criteria.
(Exerpt from 1989 AASHTO *Guide Specifications for Bridge Railings*)[2]

	TEST SPEEDS—mph[1,2]			
	TEST VEHICLE DESCRIPTIONS AND IMPACT ANGLES			
PERFORMANCE LEVELS	Small Automobile W = 1.8 Kips A = 5.4' ± 0.1' B = 5.5' H_{cg} = 20" ± 1" θ = 20 deg.	Pickup Truck W = 5.4 Kips A = 8.5' ± 0.1' B = 6.5' H_{cg} = 27" ± 1" θ = 20 deg.	Medium Single-Unit Truck W = 18.0 Kips A = 12.8' ± 0.2' B = 7.5' H_{cg} = 49" ± 1" θ = 15 deg.	Van-Type Tractor-Trailer[4] W = 50.0 Kips A = 12.5' ± 0.5' B = 8.0' H_{cg} = See Note 4 R = 0.61 ± 0.01 θ = 15 deg.
PL-1	50	45		
PL-2	60	60	50	
PL-3	60	60		50
CRASH TEST EVALUATION CRITERIA[3] Required	a, b, c, d, g	a, b, c, d	a, b, c	a, b, c
Desirable[5]	e, f, h	e, f, g, h	d, e, f, h	d, e, f, h

Notes:
1. Except as noted, all full-scale tests shall be conducted and reported in accordance with the requirements in NCHRP Report No. 230. In addition, the maximum loads that can be transmitted from the bridge railing to the bridge deck are to be determined from static force measurements or ultimate strength analysis and reported.
2. Permissible tolerances on the test speeds and angles are as follows:

$$\text{Speed} \quad -1.0 \text{ mph} \quad +2.5 \text{ mph}$$
$$\text{Angle} \quad -1.0 \text{ deg.} \quad +2.5 \text{ deg.}$$

Tests that indicate acceptable railing performance but that exceed the allowable upper tolerances will be accepted.
3. Criteria for evaluating bridge railing crash test results are as follows:
   a. The test article shall contain the vehicle; neither the vehicle nor its cargo shall penetrate or go over the installation. Controlled lateral deflection of the test article is acceptable.
   b. Detached elements, fragments, or other debris from the test article shall not penetrate or show potential for penetrating the passenger compartment or present undue hazard to other traffic.
   c. Integrity of the passenger compartment must be maintained with no intrusion and essentially no deformation.
   d. The vehicle shall remain upright during and after collision.
   e. The test article shall smoothly redirect the vehicle. A redirection is deemed smooth if the rear of the vehicle or, in the case of a combination vehicle, the rear of the tractor or trailer does not yaw more than 5 degrees away from the railing from time of impact until the vehicle separates from the railing.
   f. The smoothness of the vehicle-railing interaction is further assessed by the effective coefficient of friction, μ:

μ	Assessment
0–0.25	Good
0.26–0.35	Fair
>0.35	Marginal

where $\mu = (\cos\theta - V_p/V)/\sin\theta$

Table 5. Bridge railing performance levels and crash test criteria.
(Exerpt from 1989 AASHTO *Guide Specifications for Bridge Railings*)[2]
(continued)

g. The impact velocity of a hypothetical front-seat passenger against the vehicle interior, calculated from vehicle accelerations and 2.0-ft. longitudinal and 1.0-ft. lateral diplacements, shall be less than:

Occupant Impact Velocity–fps	
Longitudinal	Lateral
30	25

and the vehicle highest 10-ms average accelerations subsequent to the instant of hypothetical passenger impact should be less than:

Occupant Ridedown Acceleration—g's	
Longitudinal	Lateral
15	15

h. Vehicle exit angle from the barrier shall not be more than 12 degrees. Within 100 ft. plus the length of the test vehicle from the point of initial impact with the railing, the railing side of the vehicle shall move no more than 20-ft. from the line of the traffic face of the railing. The brakes shall not be applied until the vehicle has traveled at least 100-ft. plus the length of the test vehicle from the point of initial impact.

4. Values A and R are estimated values describing the test vehicle and its loading. Values of A and R are described in the figure below and calculated as follows:

Min. Load = 20.5 Kips

$L_1 = 30'' \pm 1''$

$L_2 + \dfrac{L_3}{2} = 169'' \pm 4''$

$A = L_1 + \dfrac{W_2 L_2 + W_3(L_2 + L_3)}{W_1 + W_2 + W_3}$

$R = \dfrac{W_1 + W_2 + W_3}{W}$

$W = W_1 + W_2 + W_3 + W_4 + W_5$
= total vehicle weight.

4.5' Approx. (Rear most setting.)

H_{cg} (Load) = 92'' Approx.

H_{cg} (Trailer & Load) = 79'' ± 1''

H_{cg} (Tractor, Trailer, & Load) = 64'' ± 2''

5. Test articles that do not meet the desirable evaluation criteria shall have their performance evaluated by a designated authority that will decide whether the test article is likely to meet its intended use requirements.

1 mi = 1.61 km
1 kip = 4.45 kN
1 in = 25.4 mm

56

0.000 s

0.182 s

0.364 s

0.546 s

Figure 37. Sequential photographs for test 7069-8.
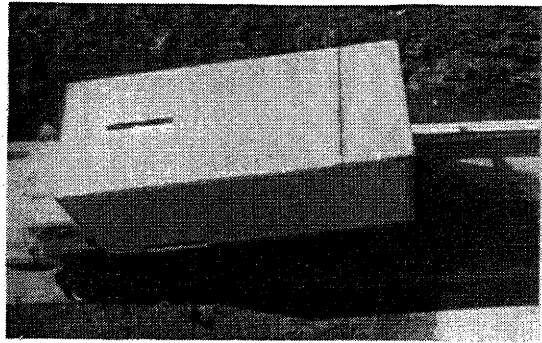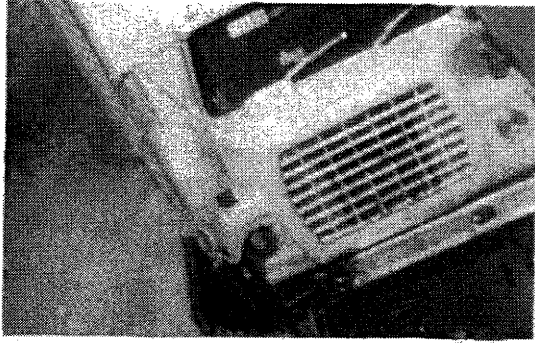
0.727 s
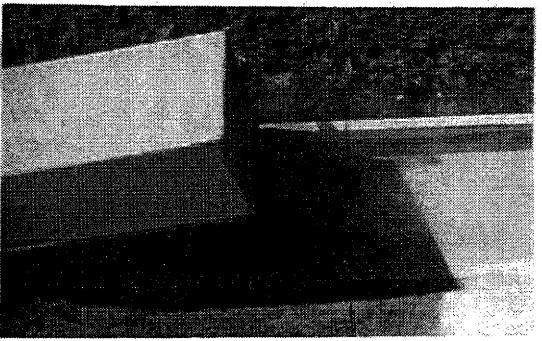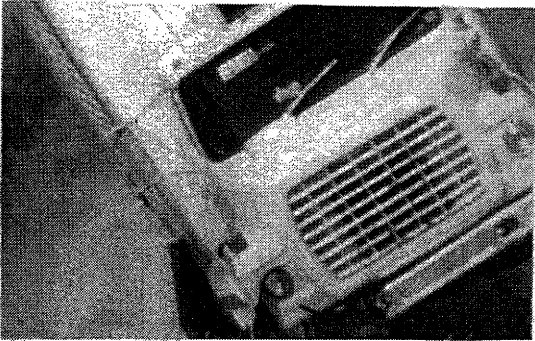
0.909 s
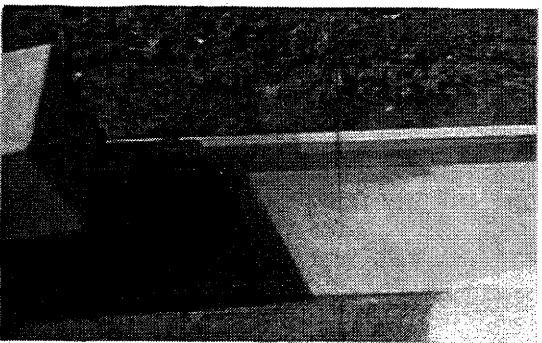
1.091 s
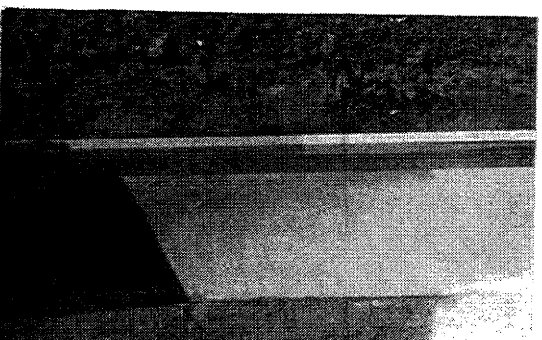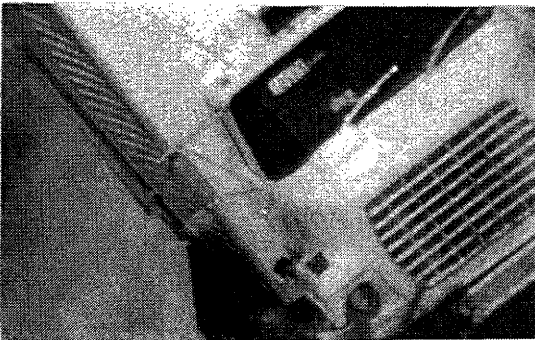
1.273 s

Figure 37. Sequential photographs for test 7069-8 (continued).
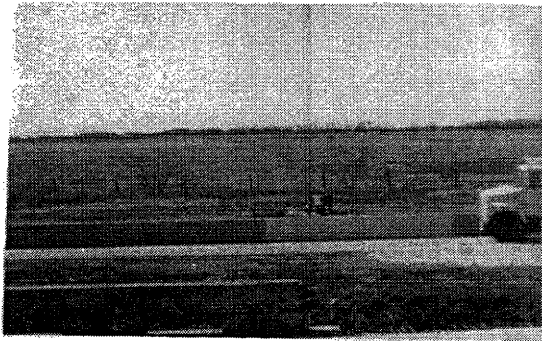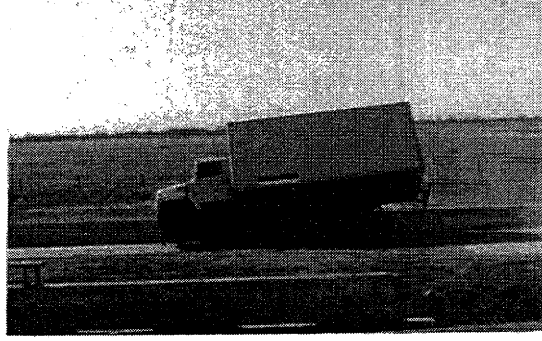
0.000 s   0.727 s
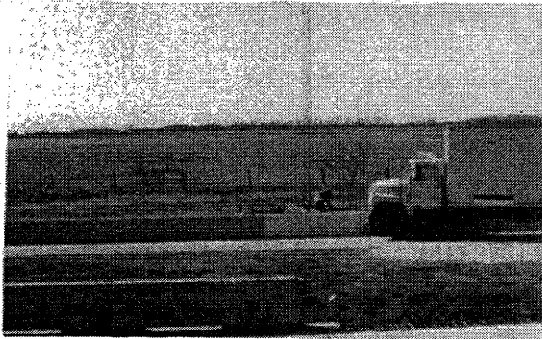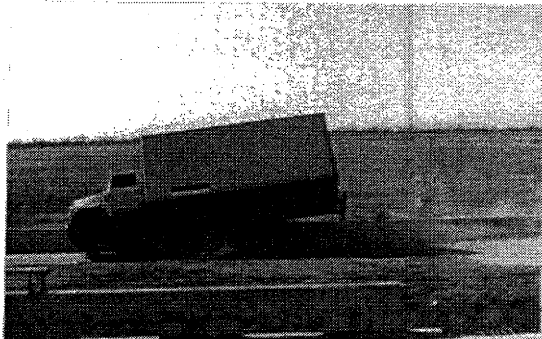
0.182 s   0.909 s
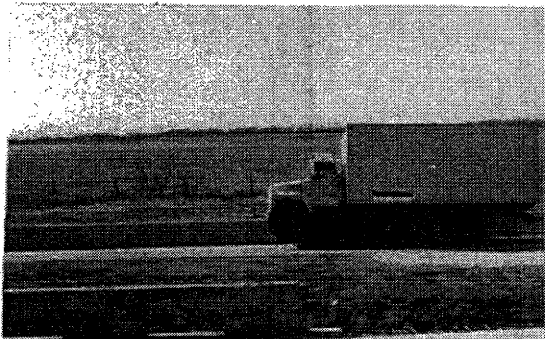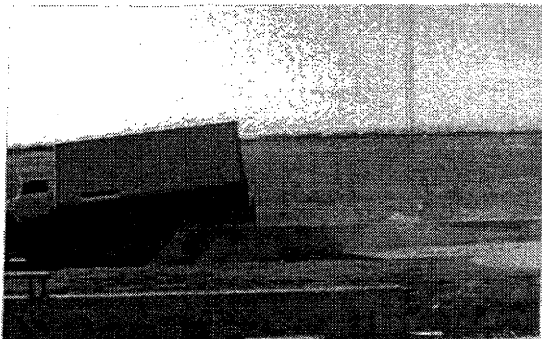
0.364 s   1.091 s
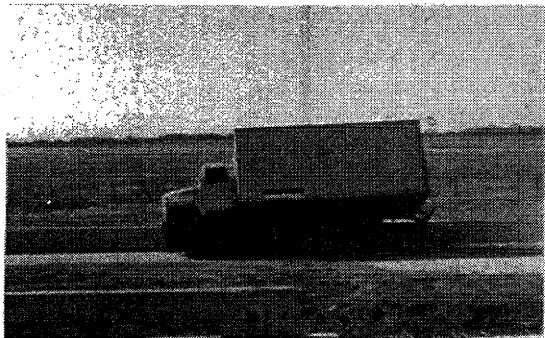
0.546 s   1.273 s

Figure 38.   Perpendicular sequential photographs for test 7069-8.
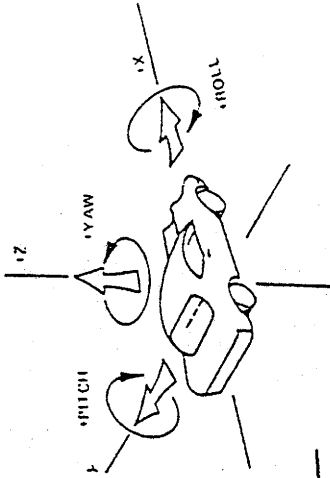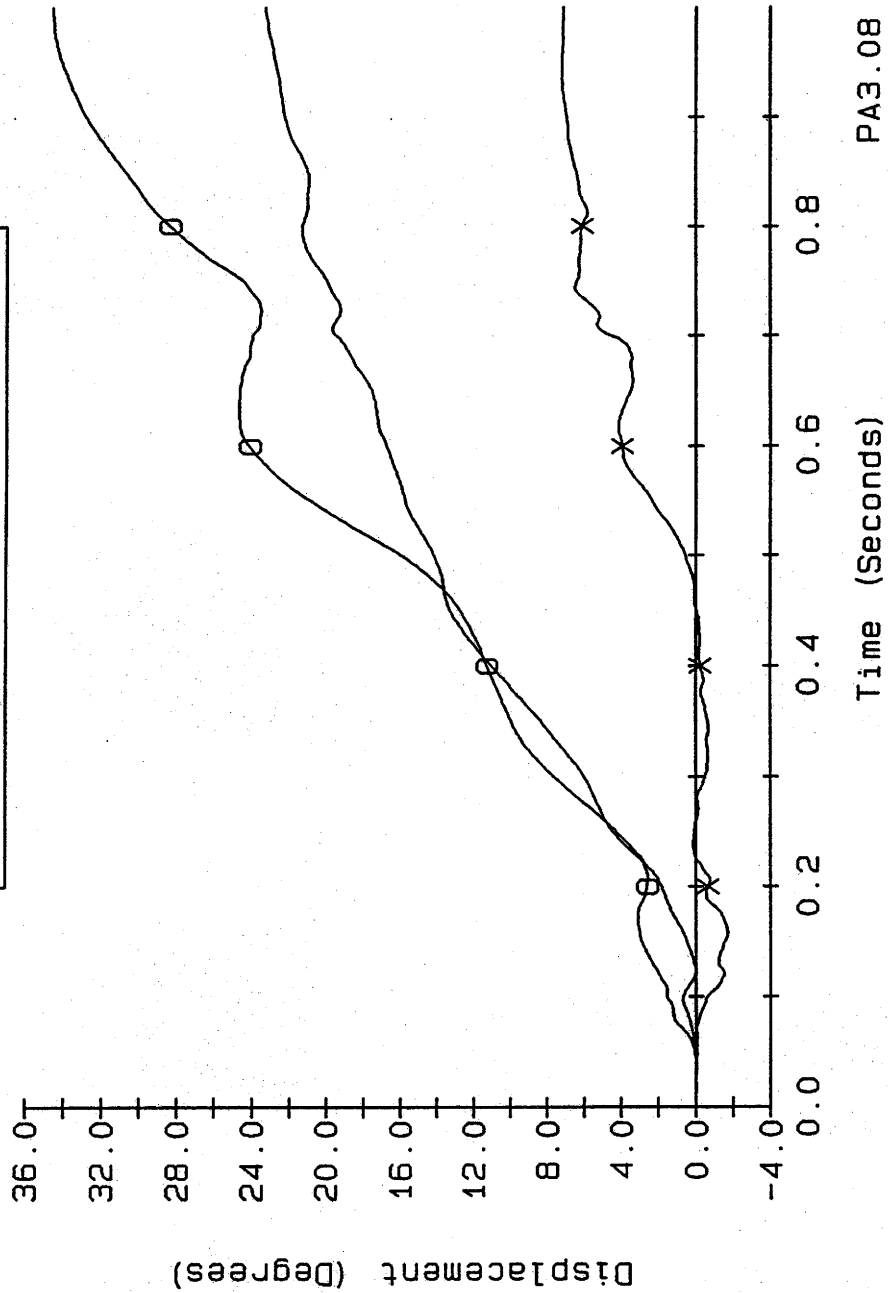
Figure 39. Vehicle angular displacements for test 7069-8.

60

CRASH TEST 7069-8

Accelerometer near center-of-gravity

Test Article: 32-in F-Shape
Test Vehicle: 1982 Ford Single-Unit Truck
Empty Weight: 13,050 lb
Test Inertia Weight: 18,050 lb
Test Speed: 46.7 mi/h
Test Angle: 15.0 degrees

1 in = 25.4 mm
1 lb = 0.454 kg
1 mi/h = 1.609 km/h

Class 180 filter
50-msec Average

TIME AFTER IMPACT (SECONDS)

LONGITUDINAL ACCELERATION (g's)
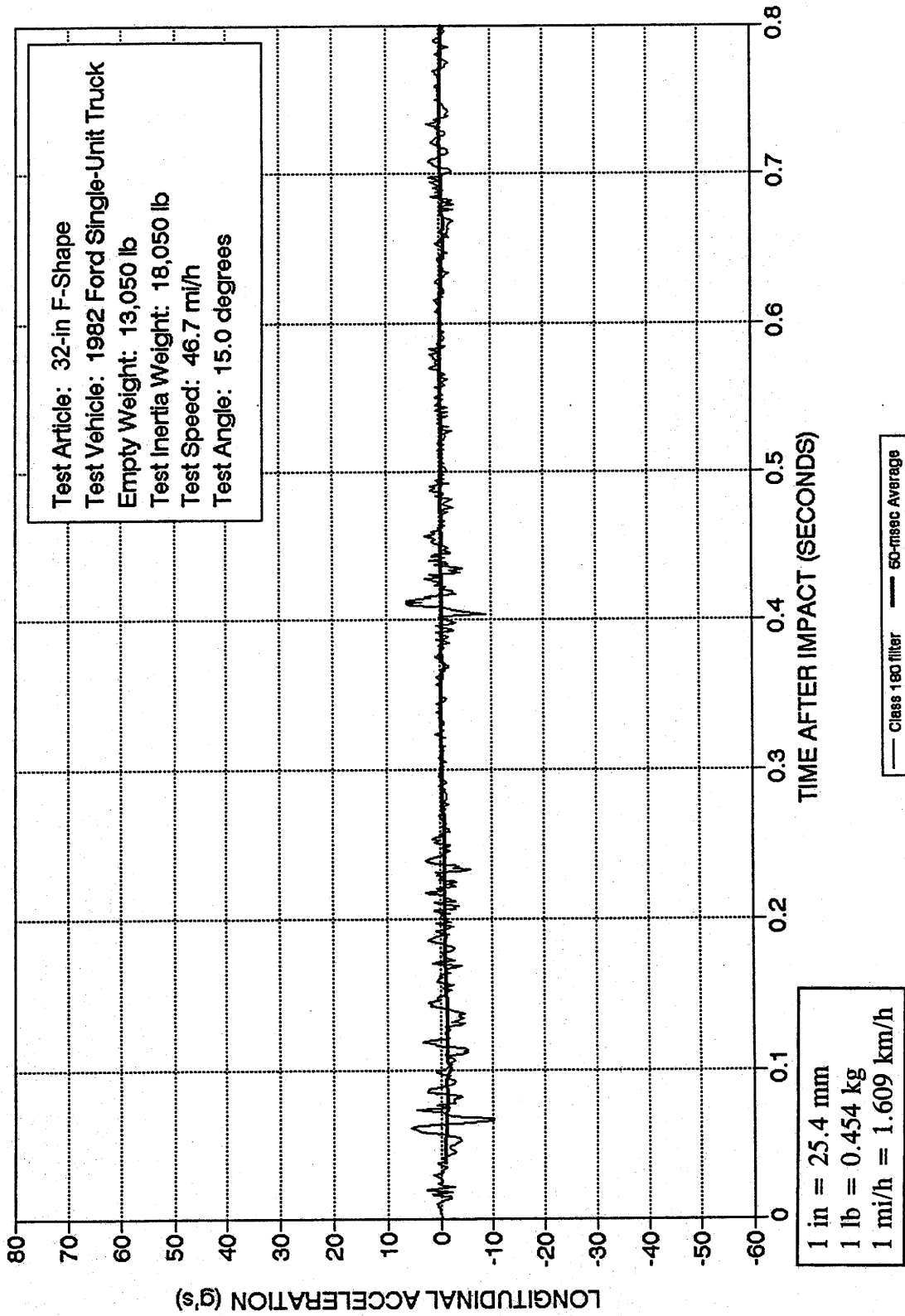
Figure 40. Vehicle longitudinal accelerometer trace for test 7069-8 (accelerometer located near center-of-gravity).
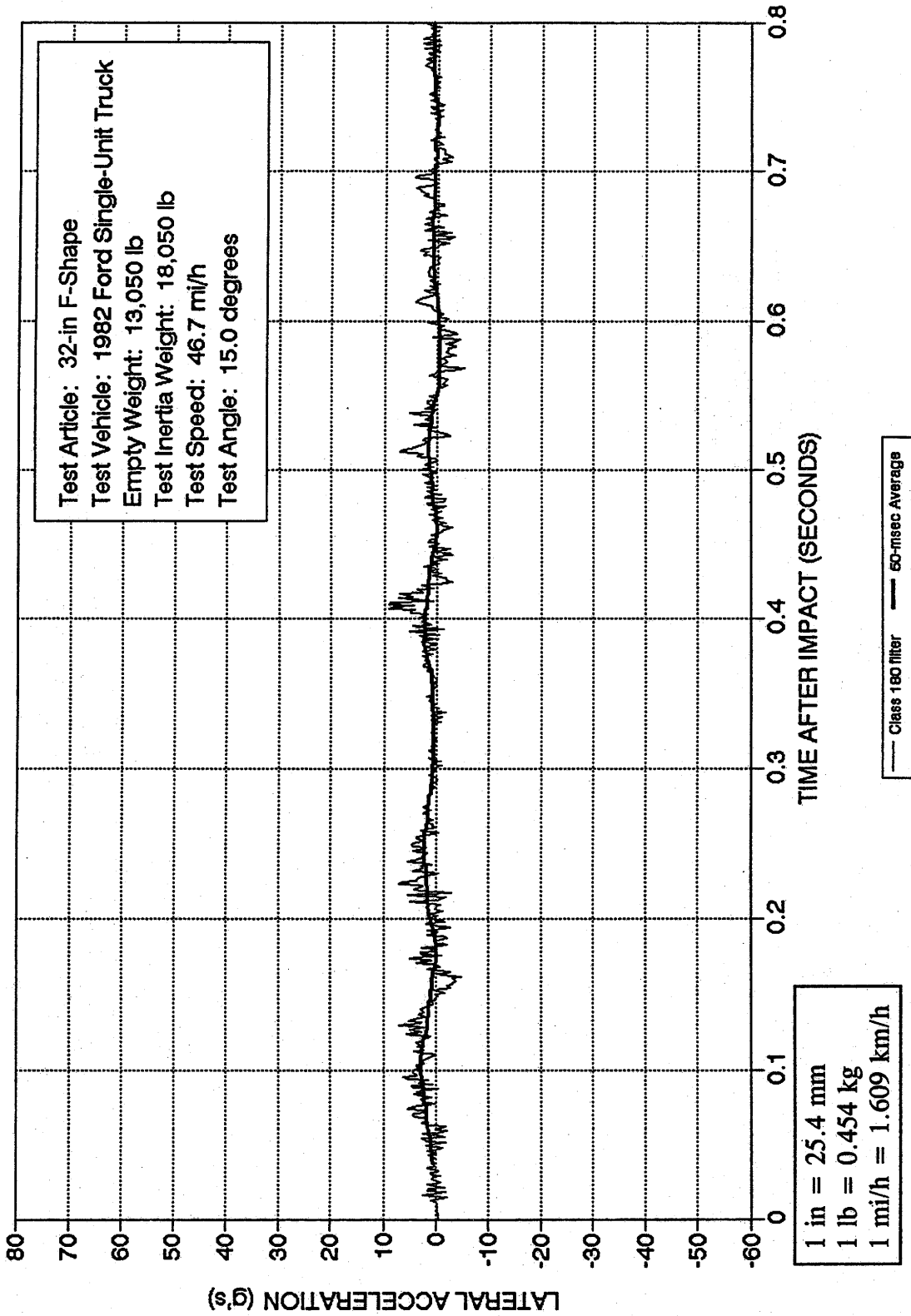
Figure 41. Vehicle lateral accelerometer trace for test 7069-8 (accelerometer located near center-of-gravity).
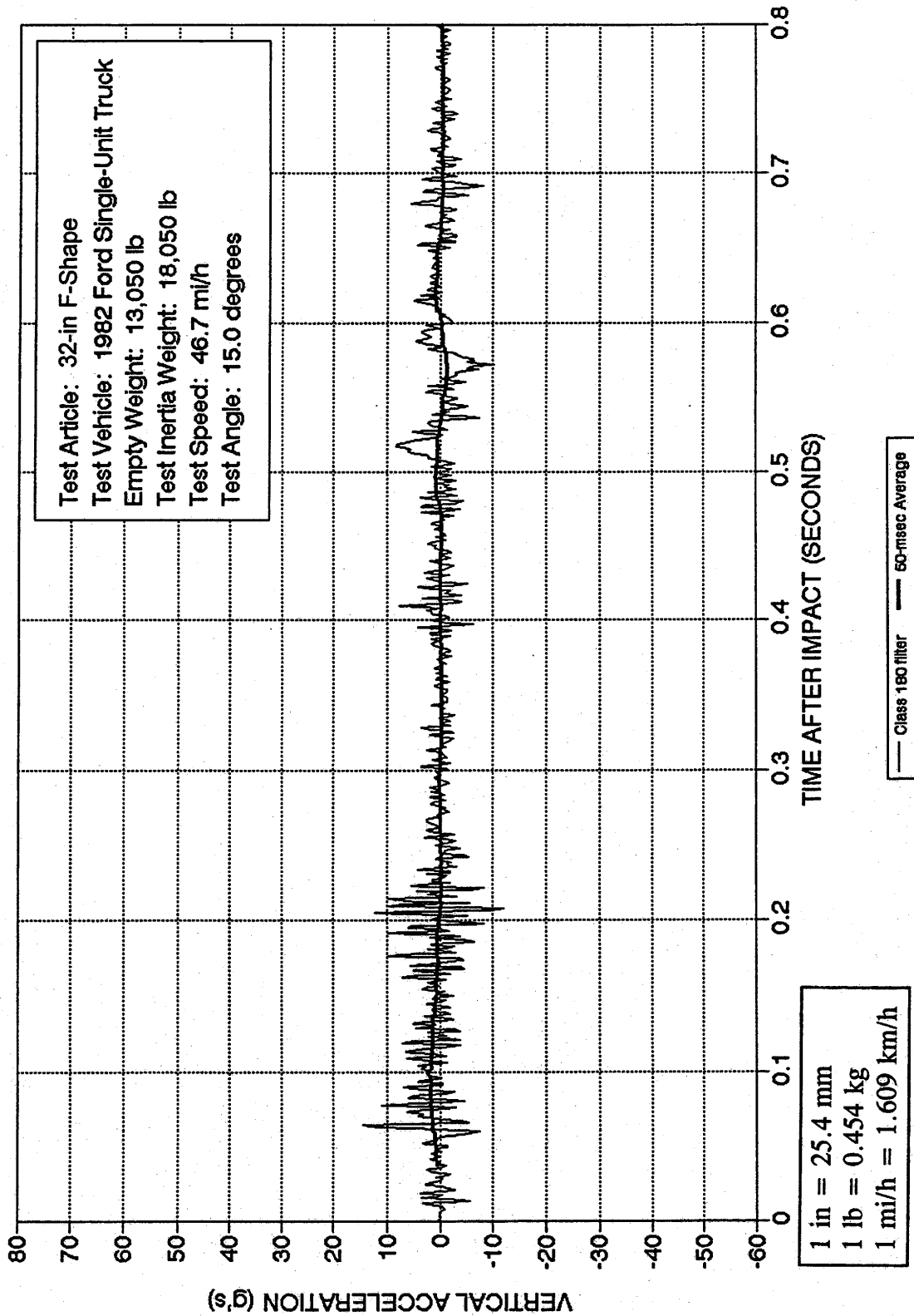
Figure 42. Vehicle vertical accelerometer trace for test 7069-8 (accelerometer located near center-of-gravity).

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CRASH TEST 7069-8
Accelerometer at front of vehicle

Test Article: 32-in F-Shape
Test Vehicle: 1982 Ford Single-Unit Truck
Empty Weight: 13,050 lb
Test Inertia Weight: 18,050 lb
Test Speed: 46.7 mi/h
Test Angle: 15.0 degrees

1 in = 25.4 mm
1 lb = 0.454 kg
1 mi/h = 1.609 km/h

— Class 180 filter   — 50-msec Average

TIME AFTER IMPACT (SECONDS)

LONGITUDINAL ACCELERATION (g's)
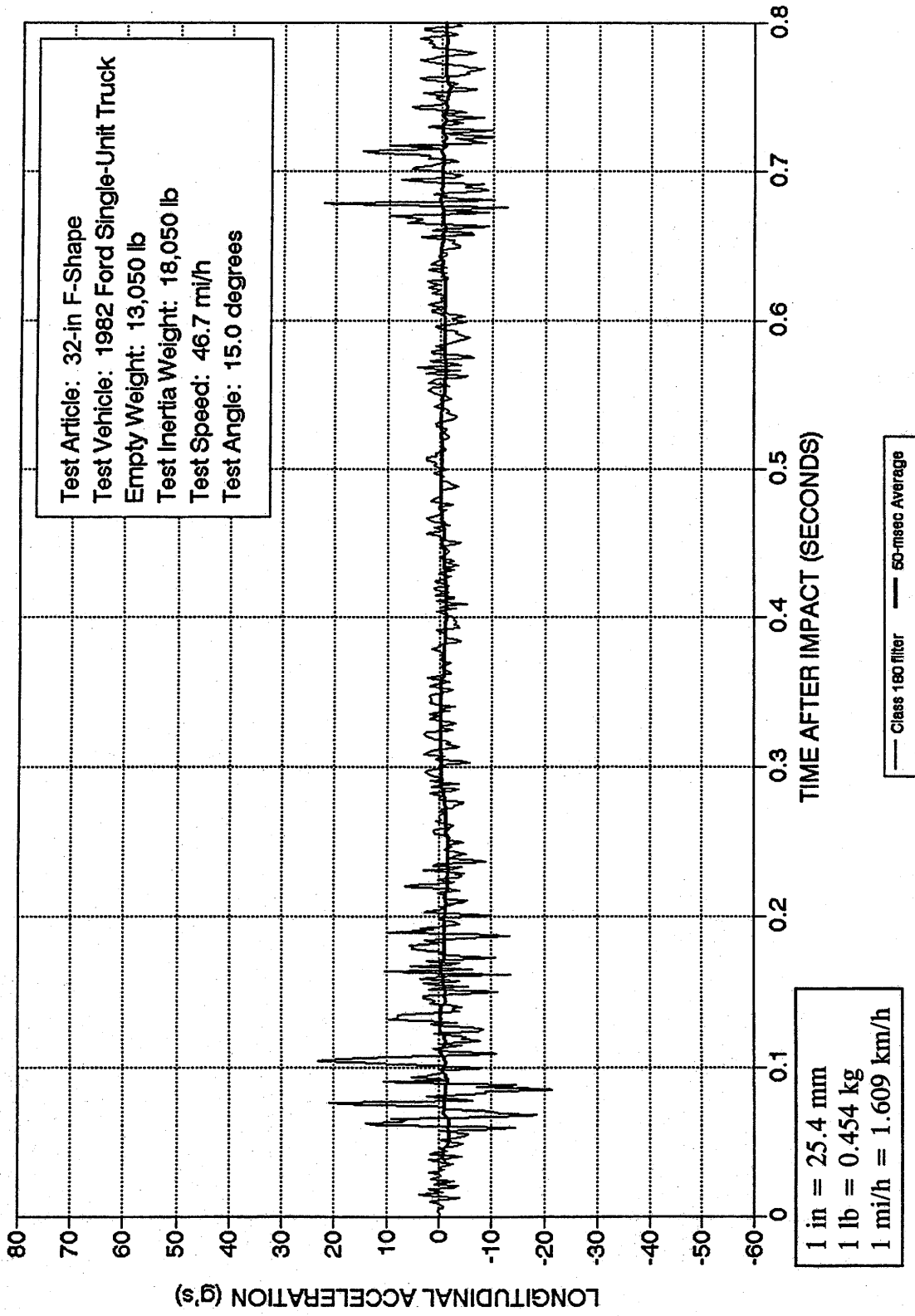
Figure 43. Vehicle longitudinal accelerometer trace for test 7069-8 (accelerometer located at front of vehicle).

64
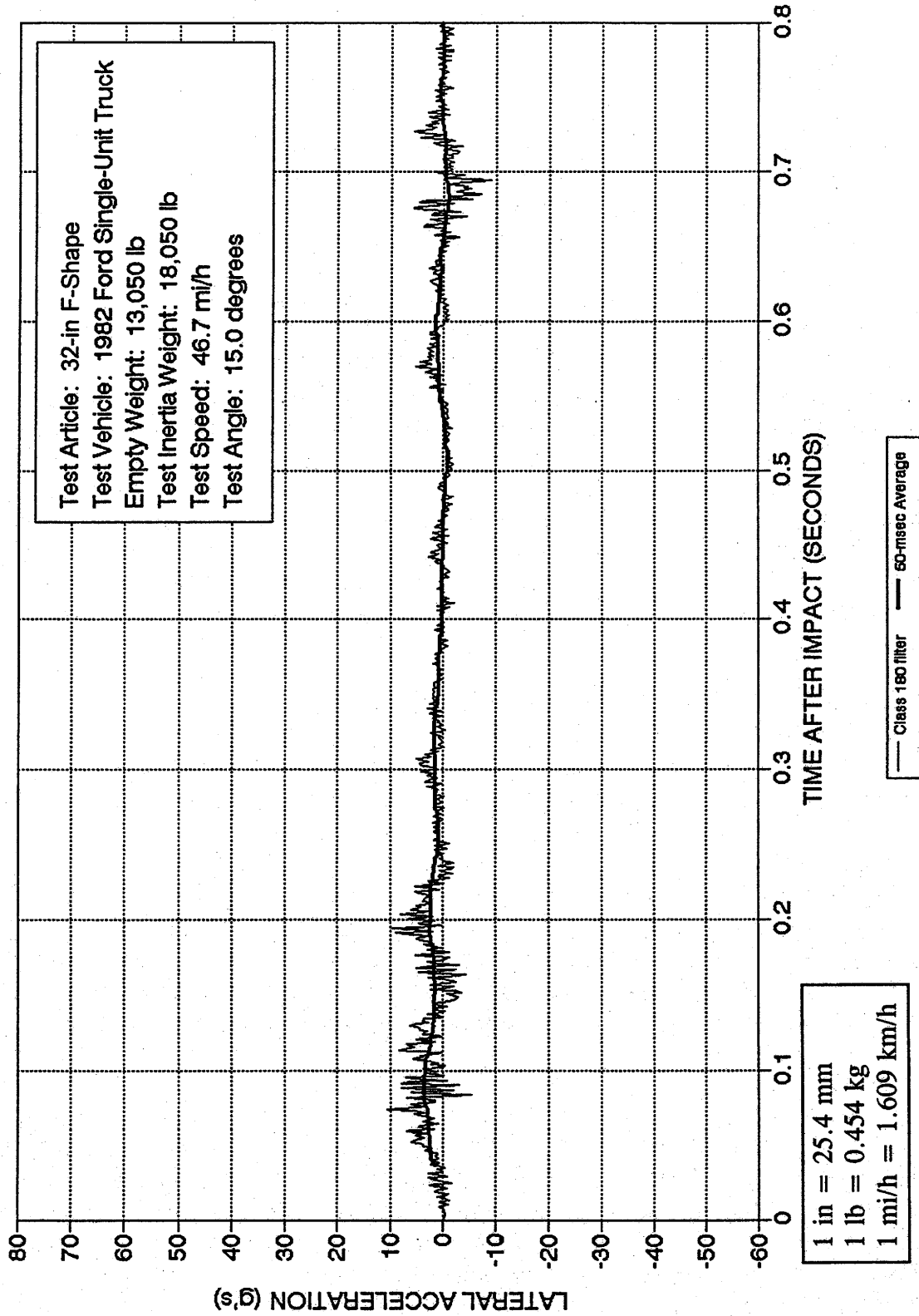
Figure 44. Vehicle lateral accelerometer trace for test 7069-8 (accelerometer located at front of vehicle).

65

TEST 7069-9

Test Description

The 1982 Ford single-unit truck (figures 45 and 46) was directed into the bridge railing (figure 47) using a remote controlled guidance system. Empty weight of the vehicle was 13,850 lb (6 288 kg) and its test inertia weight was 18,050 lb (8 195 kg). The height to the lower edge of the vehicle bumper was 19.25 in (489 mm) and it was 28.00 in (711 mm) to the top of the bumper. Other dimensions and information on the test vehicle are given in figure 48. The vehicle was free-wheeling and unrestrained just prior to impact.

The speed of the vehicle at impact was 47.3 mi/h (76.1 km/h) and the angle of impact was 15.3 degrees. The vehicle impacted the bridge railing at midlength. At approximately 0.017 s after impact the right front wheel began to ride up the face of the bridge railing, and at 0.153 s the left front tire began to leave the ground. The vehicle began to redirect at 0.156 s as the rear end began to slide toward the bridge railing. At 0.292 s the left rear wheels left the ground, and at 0.421 s the rear of the vehicle slapped the bridge railing. By approximately 0.523 s the vehicle became parallel with the railing and was continuing to roll to the right. As the vehicle continued along the railing, the lower edge of the bed rode along the top of the railing. A maximum roll angle of 25 degrees was achieved at about 0.886 s. The vehicle slid off the end of the bridge railing at about 1.326 s after impact. The brakes were applied and the vehicle subsequently came to rest 150 ft (46 m) downstream.

As can be seen in figure 49, the railing received cosmetic damage and some scraping. There were tire marks on the face of the bridge railing and along the top. The top of the bridge railing was scraped along the remaining length from the lower edge of the bed of the truck (see figure 50). The vehicle was in contact with the bridge railing for 58 ft (18 m).

The vehicle sustained extensive damage to the right side as shown in figure 51. Maximum crush at the right front corner at bumper height was 16.0 in (406 mm). The right front wheel rim was bent and the tire damaged. The spring and spring shackle were broken loose from the axle and the axle torn loose on the left side. The steering gear box and steering cylinder were damaged. Also, the fuel tank broke loose from the truck.

Test Results

Impact speed was 47.3 mi/h (76.1 km/h) and the angle of impact was 15.3 degrees. The exit speed was 34.5 mi/h (55.5 km/h). The effective coefficient of friction was calculated to be 0.09. Occupant impact velocity was 11.7 ft/s (3.6 m/s) in the longitudinal direction and 9.9 ft/s (3.0 m/s) in the lateral direction. The highest 0.010-s occupant ridedown accelerations were -2.7 g (longitudinal) and 6.8 g (lateral). These data and other pertinent information from the test are summarized in figure 52 and table 6. Sequential photographs are shown in figures 53 and 54. Vehicle angular displacements are displayed in figure 55. Vehicular accelerations versus time traces filtered with SAE J211 filters are

presented in figures 56 through 62. These data were further analyzed to obtain 0.050-s average accelerations versus time. A 0.050-s interval immediately prior to impact was averaged to establish zero acceleration. The data were then processed with a moving 0.050-s average window with the first 0.050-s average plotted at 0.026 s. The maximum 0.050-s averages were -2.0 g (longitudinal) and 2.9 g (lateral).

Conclusions

The 32-in (813-mm) F-shape bridge railing contained and smoothly redirected the vehicle with no lateral movement of the bridge railing. There were no debris or detached elements. There was no intrusion into the occupant compartment. The vehicle trajectory at loss of contact indicated minimum intrusion into adjacent traffic lanes. The vehicle remained upright and marginally stable during the entire test period. See table 6 for a more detailed description.
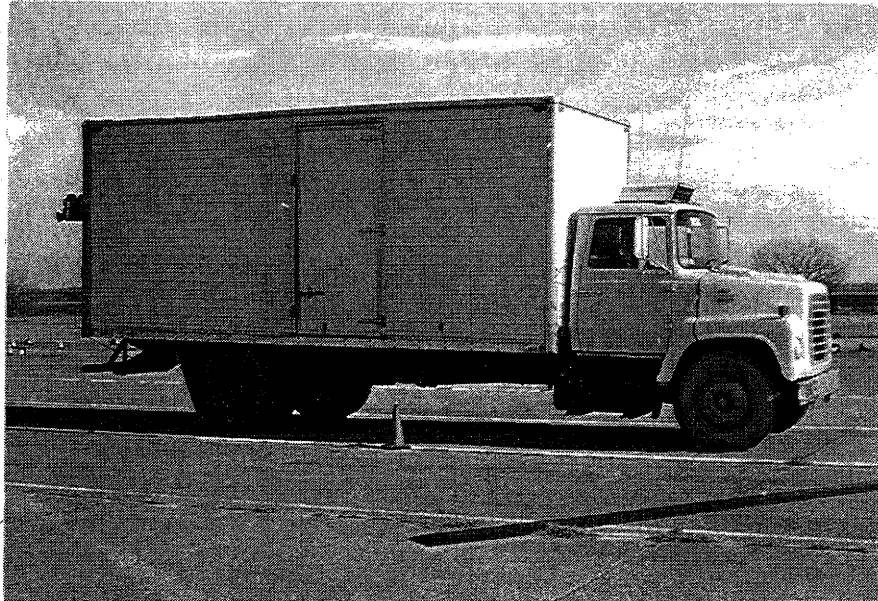
Figure 45.   Vehicle before test 7069-9.
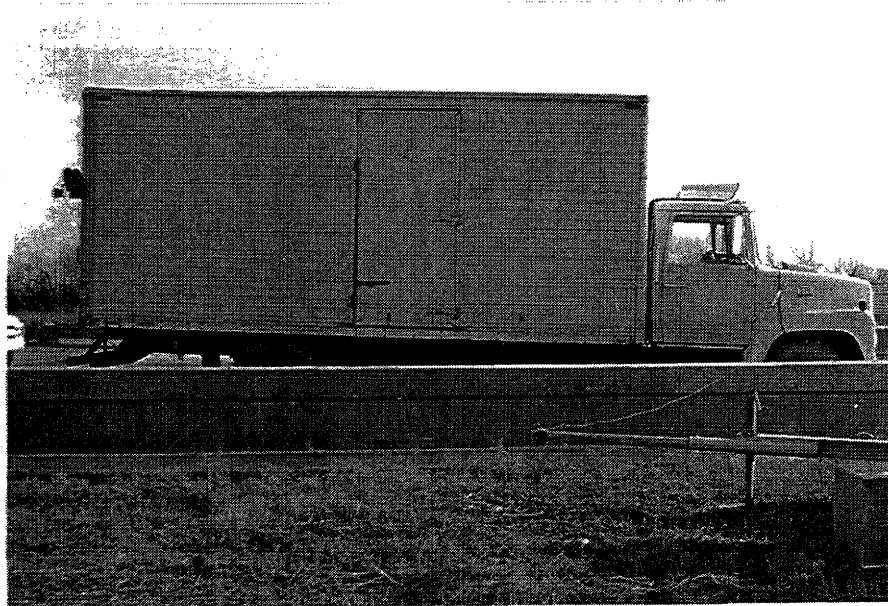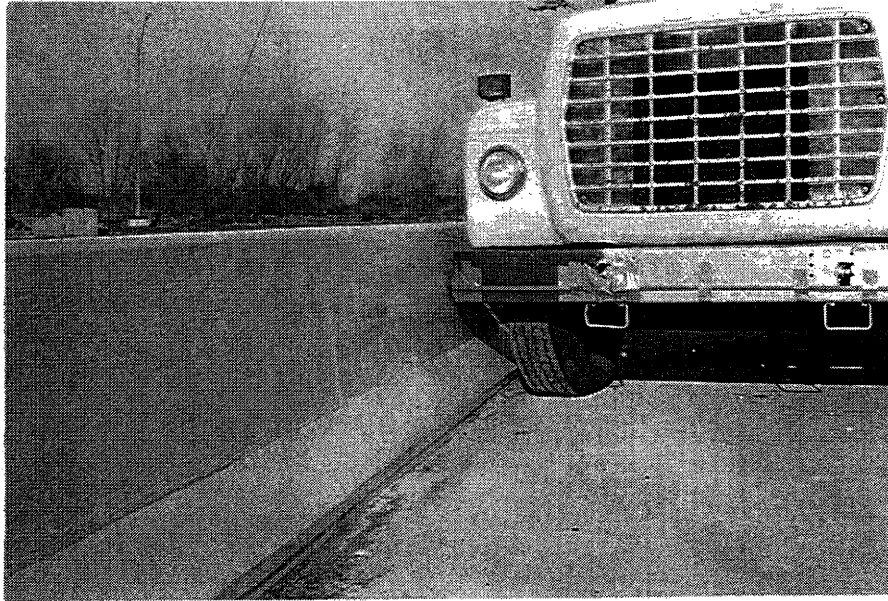
Figure 46. Vehicle/bridge railing geometrics for test 7069-9.
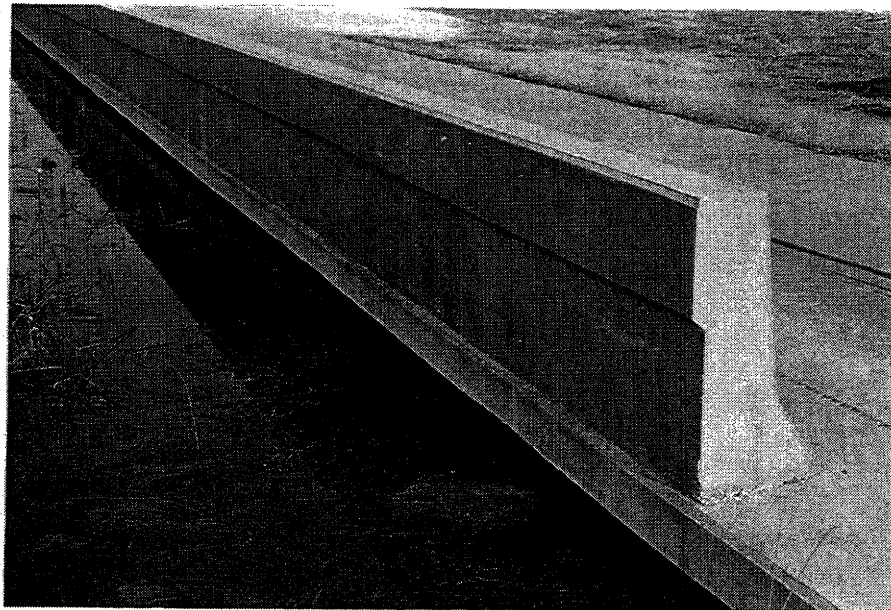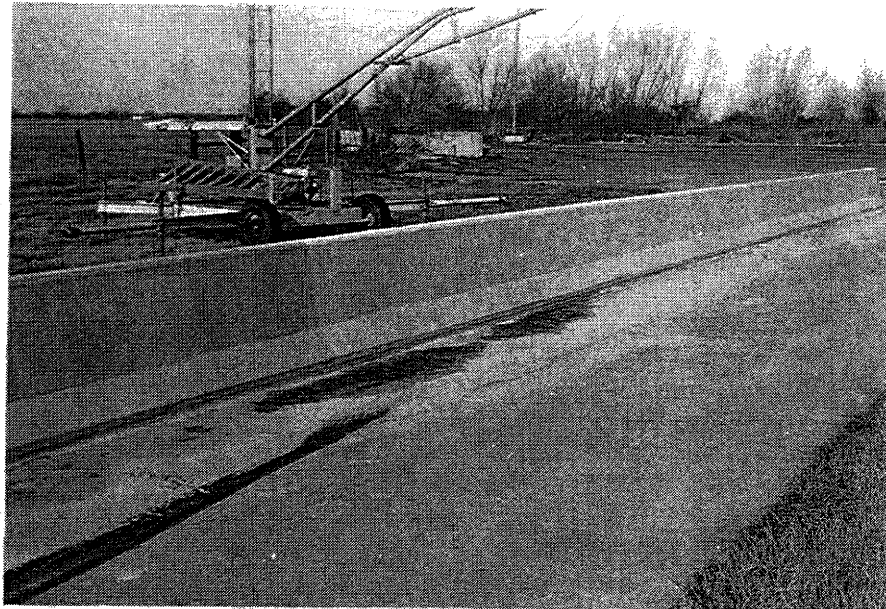
Figure 47. 32-in (813-mm) F-shape bridge railing before test 7069-9.
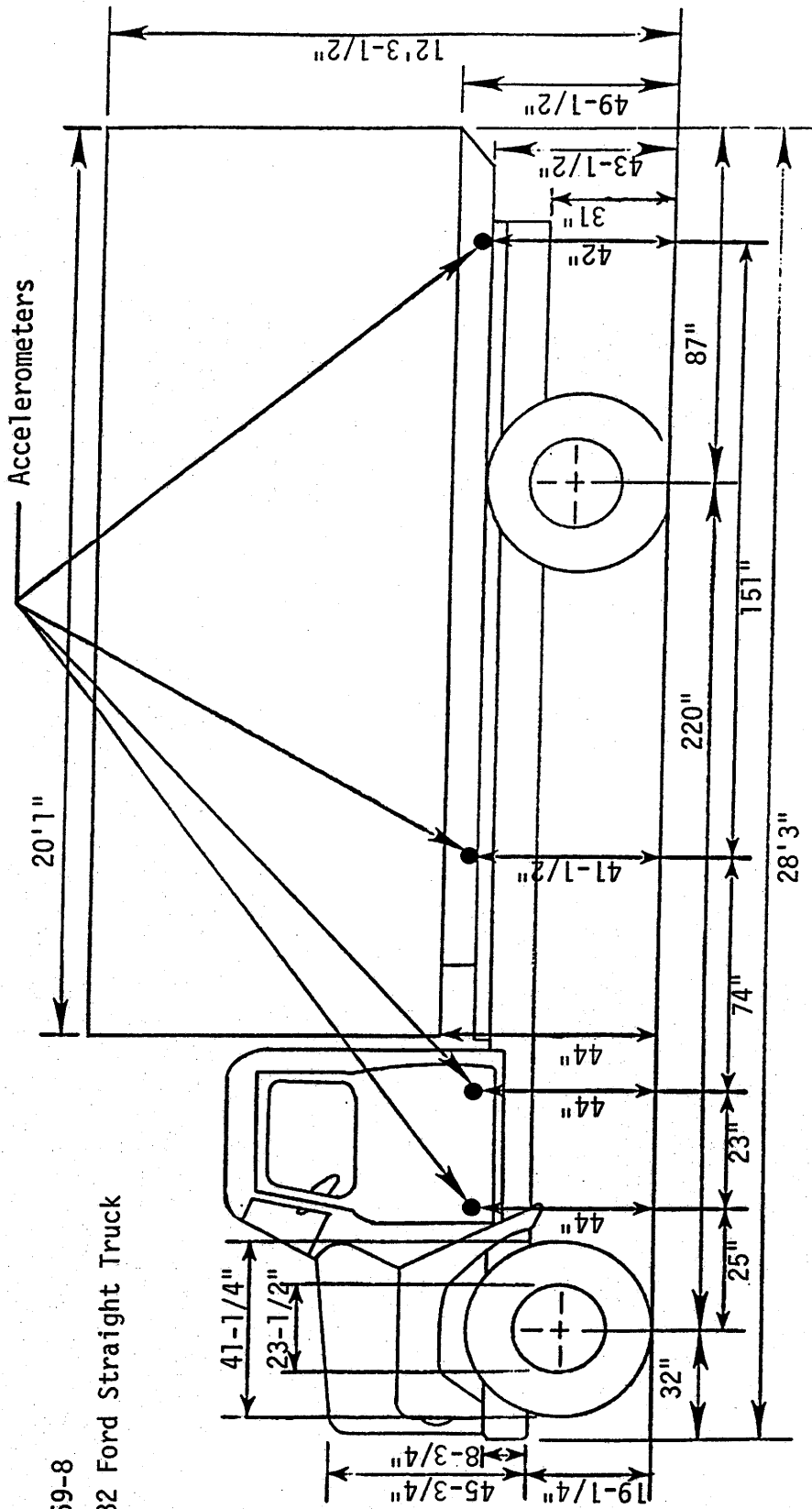
7069-8
1982 Ford Straight Truck

Accelerometers

20'1"

12'3-1/2"

49-1/2"

43-1/2"

31"

42"

87"

220"

151"

28'3"

41-1/2"

74"

44"

44"

23"

44"

25"

32"

41-1/4"

23-1/2"

8-3/4"

45-3/4"

19-1/4"

EMPTY WEIGHTS

Weight on Front Axle : LF 3,420   RF 3,630

Weight on Rear Axle : LR 3,520   RR 3,280

TOTAL EMPTY WEIGHT : 13,850

LOADED WEIGHTS

Weight on Front Axle :   7,820

Weight on Rear Axle :   10,230

TOTAL LOADED WEIGHT :   18,050

1 in = 25.4 mm

Figure 48. Vehicle properties for test 7069-9.

71
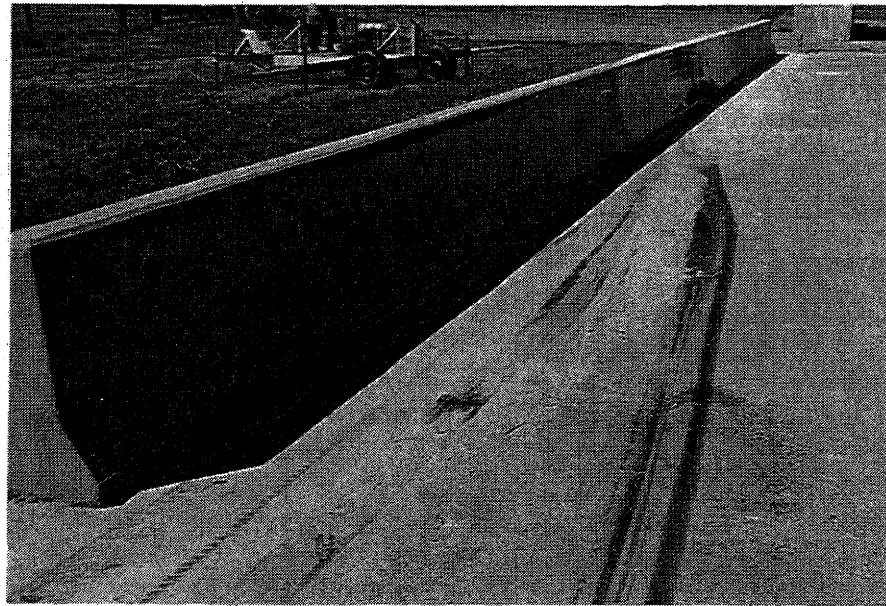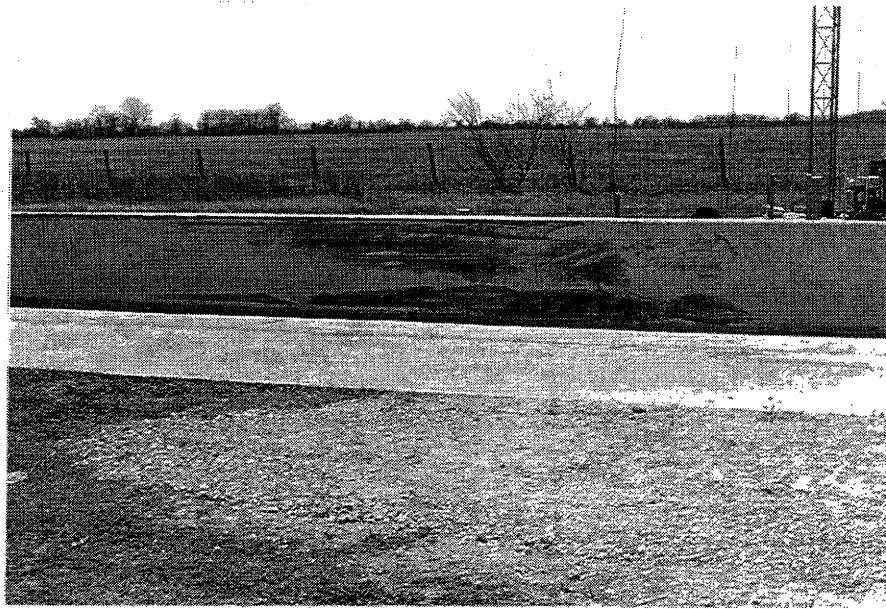
Figure 49. 32-in (813-mm) F-shape bridge railing after test 7069-9.
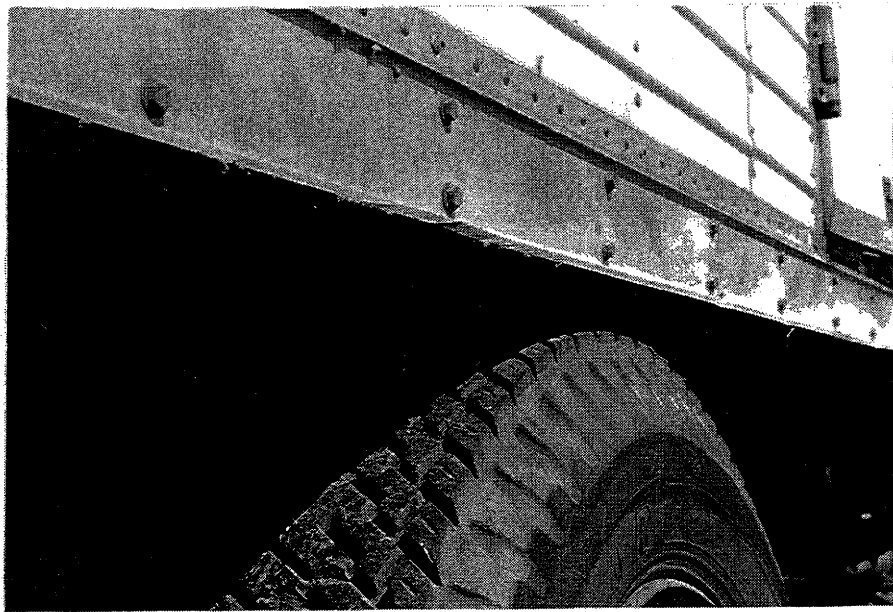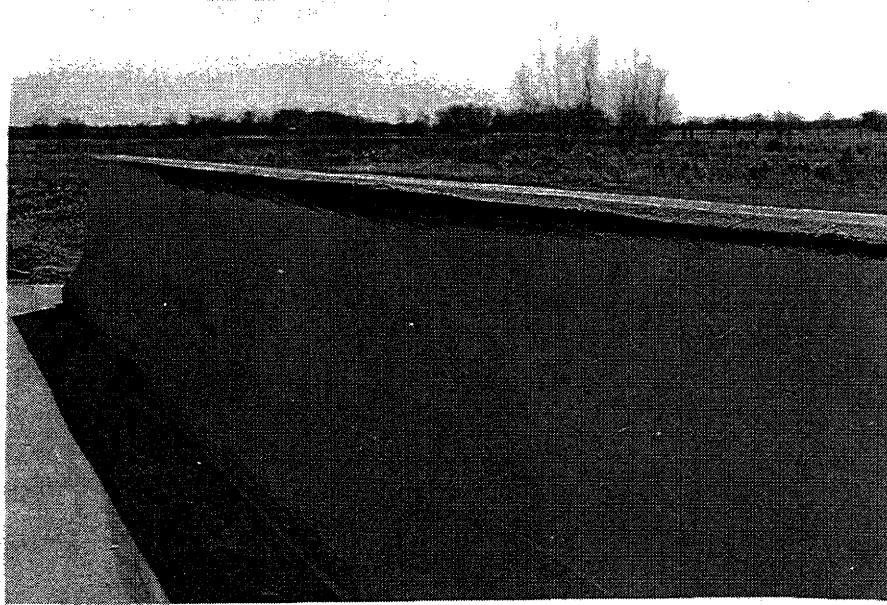
Figure 50.   Damage to top of bridge railing and to lower edge truck bed.

Figure 51. Vehicle after test 7069-9.

74

0.000 s	0.243 s	0.486 s	0.730 s

Test No. . . . . : 7069-9
Date . . . . : 2/23/88
Test Installation . . : 32-in (813-mm) F-Shape
                             Bridge Railing
Installation Length. . : 100 ft (30 m)
Vehicle . . . . : 1982 Ford
                        Single-Unit Truck
Vehicle Weight
  Empty Weight . . . . : 13,050 lb (6,288 kg)
  Test Inertia . . . . : 18,050 lb (8,195 kg)
Maximum Vehicle Crush . : 16.0 in (406 mm)

Impact Speed. . . . : 47.3 mi/h (76.1 km/h)
Impact Angle. . . . : 15.3 deg
Exit Speed. . . . . : 34.5 mi/h (55.5 km/h)
Exit Trajectory . . : 2.0 deg
Vehicle Accelerations
  (Max. 0.050-sec Avg)
  Longitudinal. . . : -2.0 g
  Lateral . . . . . : 2.9 g
Occupant Impact Velocity
  Longitudinal. . . : 11.7 ft/s (3.6 m/s)
  Lateral . . . . . : 9.9 ft/s (3.0 m/s)
Occupant Ridedown Accelerations
  Longitudinal. . . : -2.7 g
  Lateral . . . . . : 6.8 g

32 in

7 in 3 in

(1 in = 25.4 mm)

Figure 52. Summary of results for test 7069-9.

75

Table 6. Evaluation of crash test no. 7069-9.
{32 in (81 cm) F-shape Bridge Railing [18,050 lb (8 195 kg)|47.3 mi/h (76.1 km/h)|15.3 degrees]}

	CRITERIA	TEST RESULTS	PASS/FAIL
A.	Must contain vehicle	Vehicle was contained	Pass
B.	Debris shall not penetrate passenger compartment	No debris penetrated passenger compartment	Pass
C.	Passenger compartment must have essentially no deformation	Acceptable deformation	Pass
D.	Vehicle must remain upright	Vehicle remained upright	Pass
E.	Must smoothly redirect the vehicle	Vehicle was smoothly redirected	Pass

F. Effective coefficient of friction

μ	Assessment
0 - .25	Good
.26 - .35	Fair
> .35	Marginal

μ	Assessment	
.09	Good	Pass

G. Shall be less than

Occupant Impact Velocity - ft/s (m/s)

Longitudinal	Lateral
30 (9.2)	25 (7.6)

Occupant Ridedown Accelerations - g's

Longitudinal	Lateral
15	15

Occupant Impact Velocity - ft/s (m/s)

Longitudinal	Lateral	
11.7 (3.6)	9.9 (3.0)	N/A

Occupant Ridedown Accelerations - g's

Longitudinal	Lateral	
-2.7	6.8	N/A

H.	Exit angle shall be less than 12 degrees	about 2 degrees	

* A, B, C, D are required. E, F, and H are desired. G is not applicable for this test. (See table 5)

0.000 s

0.122 s
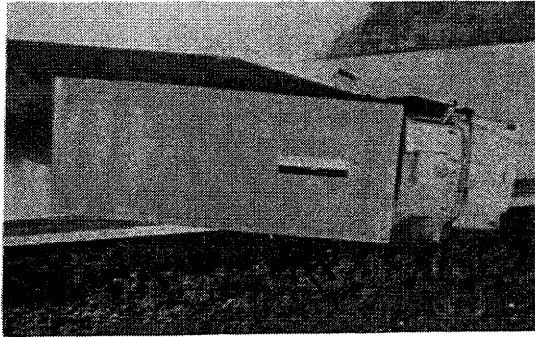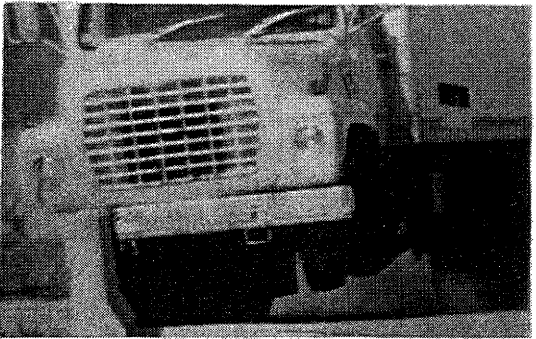
0.243 s
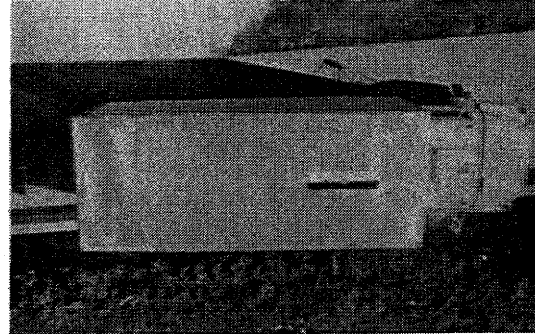
0.365 s

Figure 53.   Sequential photographs for test 7069-9.
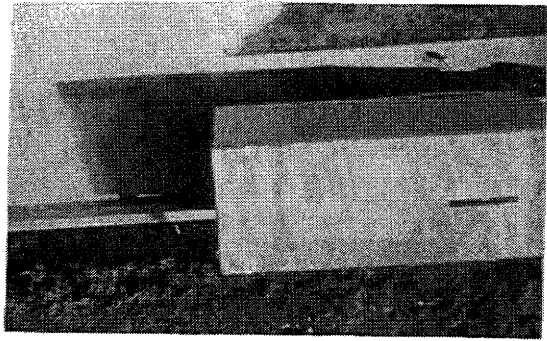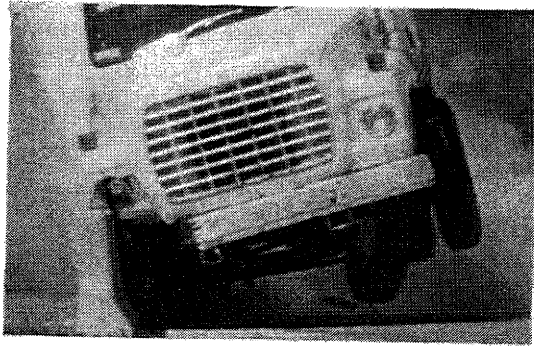
0.486 s
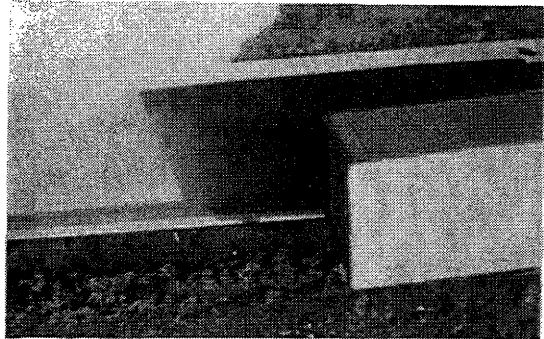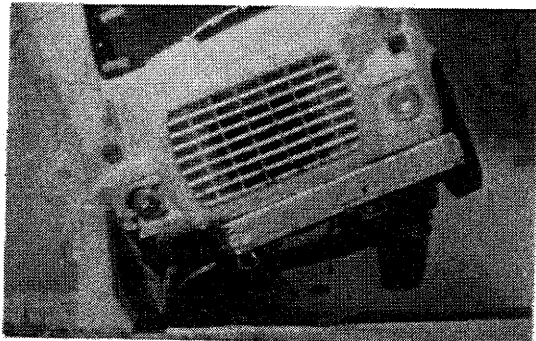
0.608 s
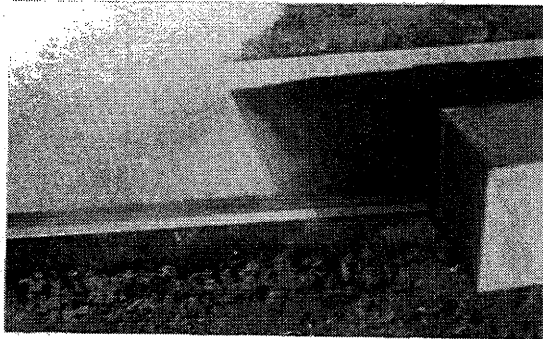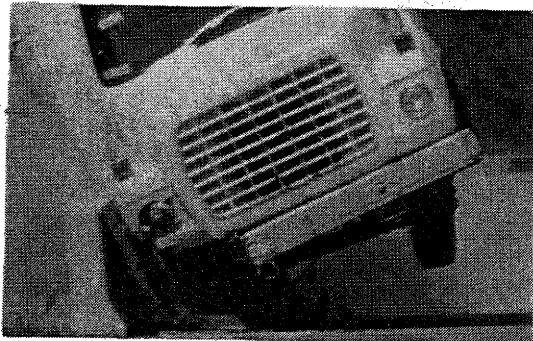
0.730 s
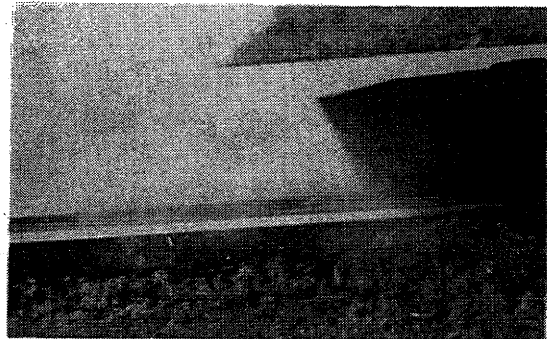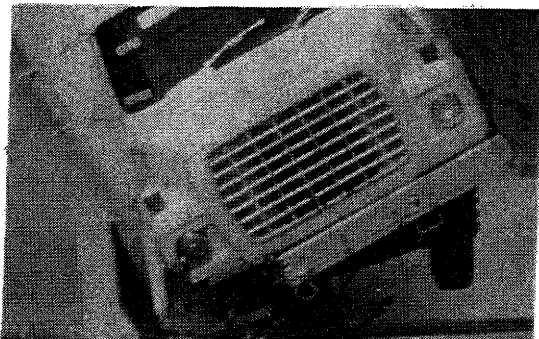
0.851 s

Figure 53. Sequential photographs for test 7069-9 (continued).
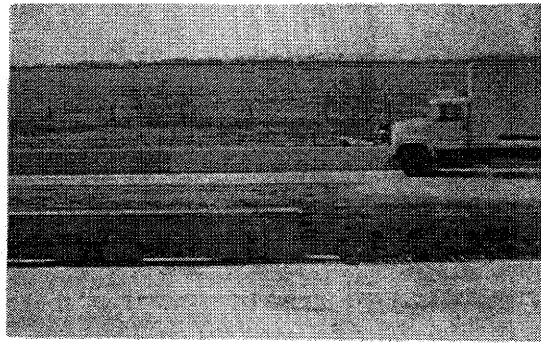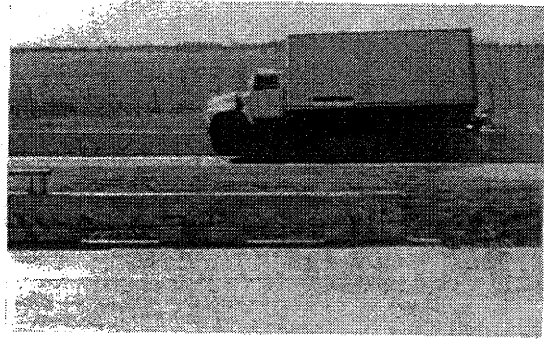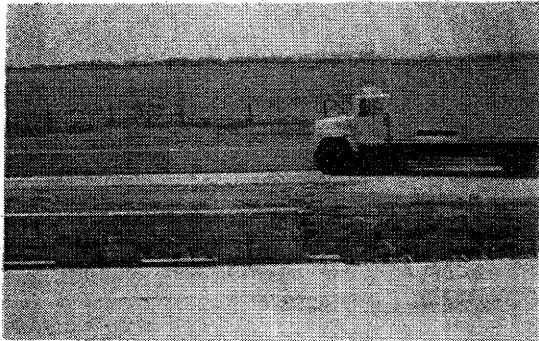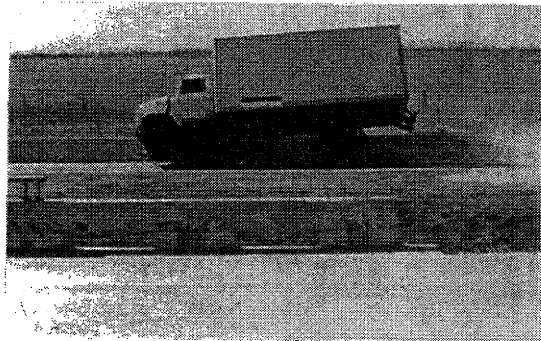
0.000 s	0.486 s
0.122 s	0.608 s
0.243 s	0.730 s
0.365 s	0.851 s
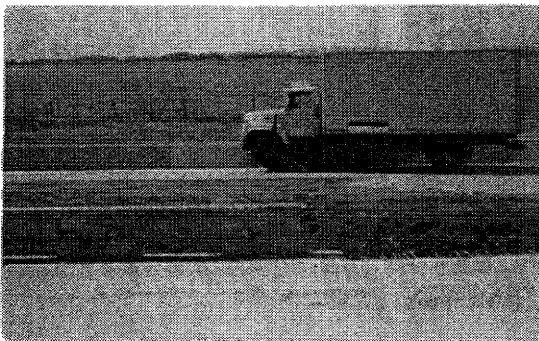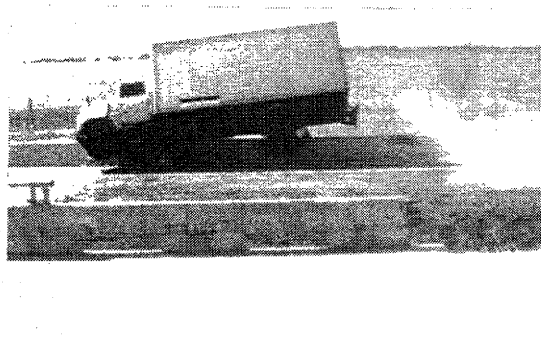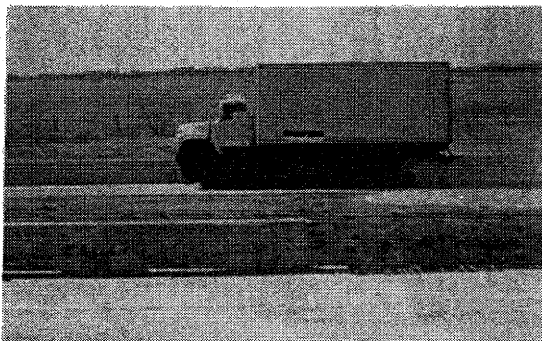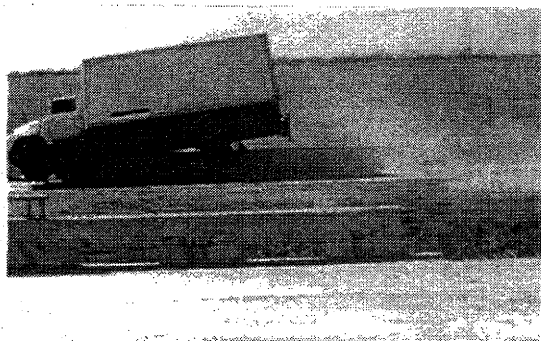
Figure 54. Perpendicular sequential photographs for test 7069-9.
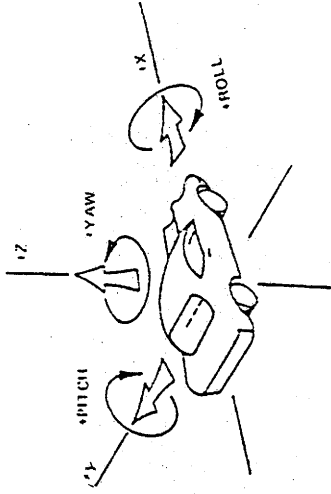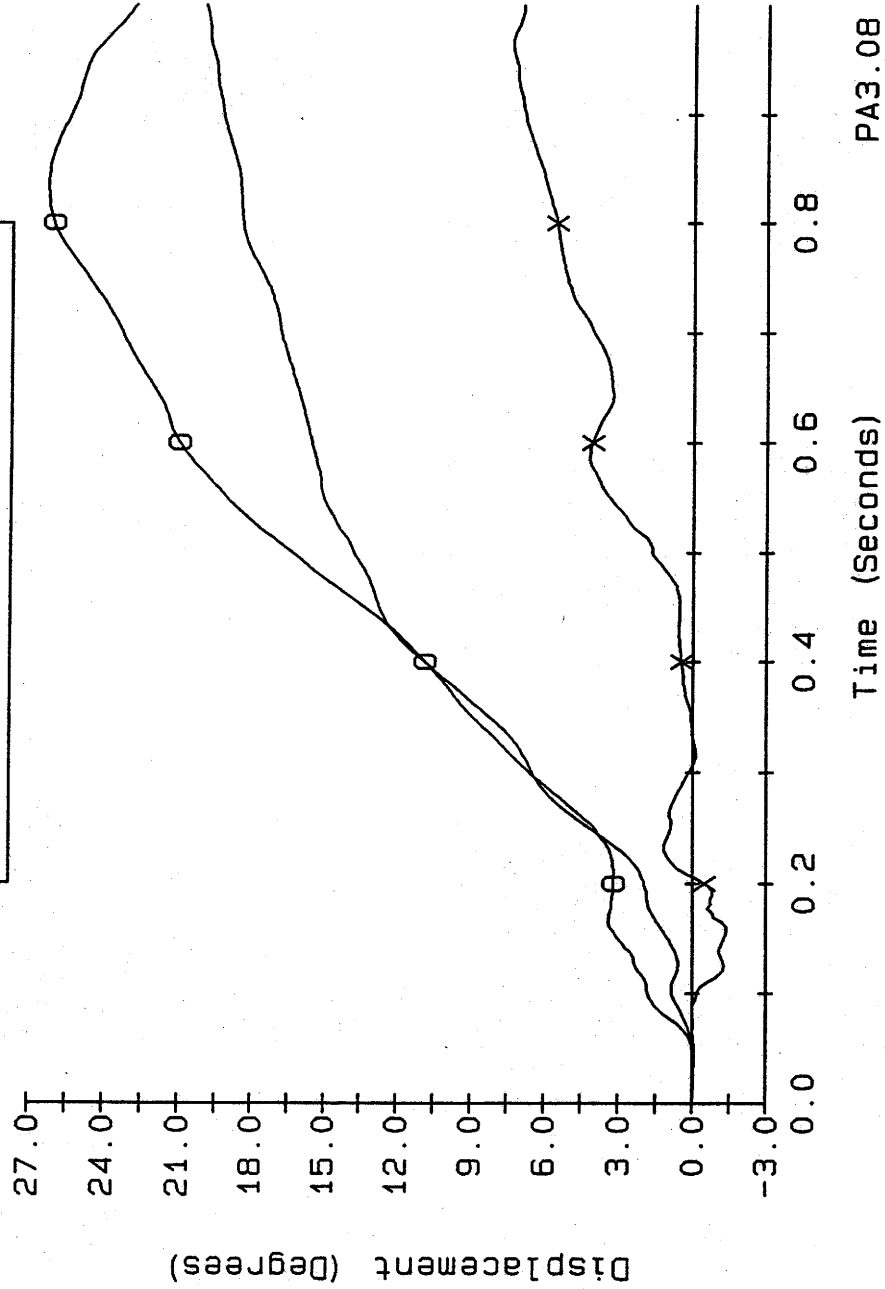
Figure 55. Vehicle angular displacements for test 7069-9.

80

CRASH TEST 7069-9
Accelerometer near center-of-gravity

Test Article: 32-in F-Shape
Test Vehicle: 1982 Ford Single-Unit Truck
Empty Weight: 13,850 lb
Test Inertia Weight: 18,050 lb
Test Speed: 47.3 mi/h
Test Angle: 15.3 degrees

LONGITUDINAL ACCELERATION (g's)

TIME AFTER IMPACT (SECONDS)

Class 180 filter ——— 50-msec Average

1 in = 25.4 mm
1 lb = 0.454 kg
1 mi/h = 1.609 km/h
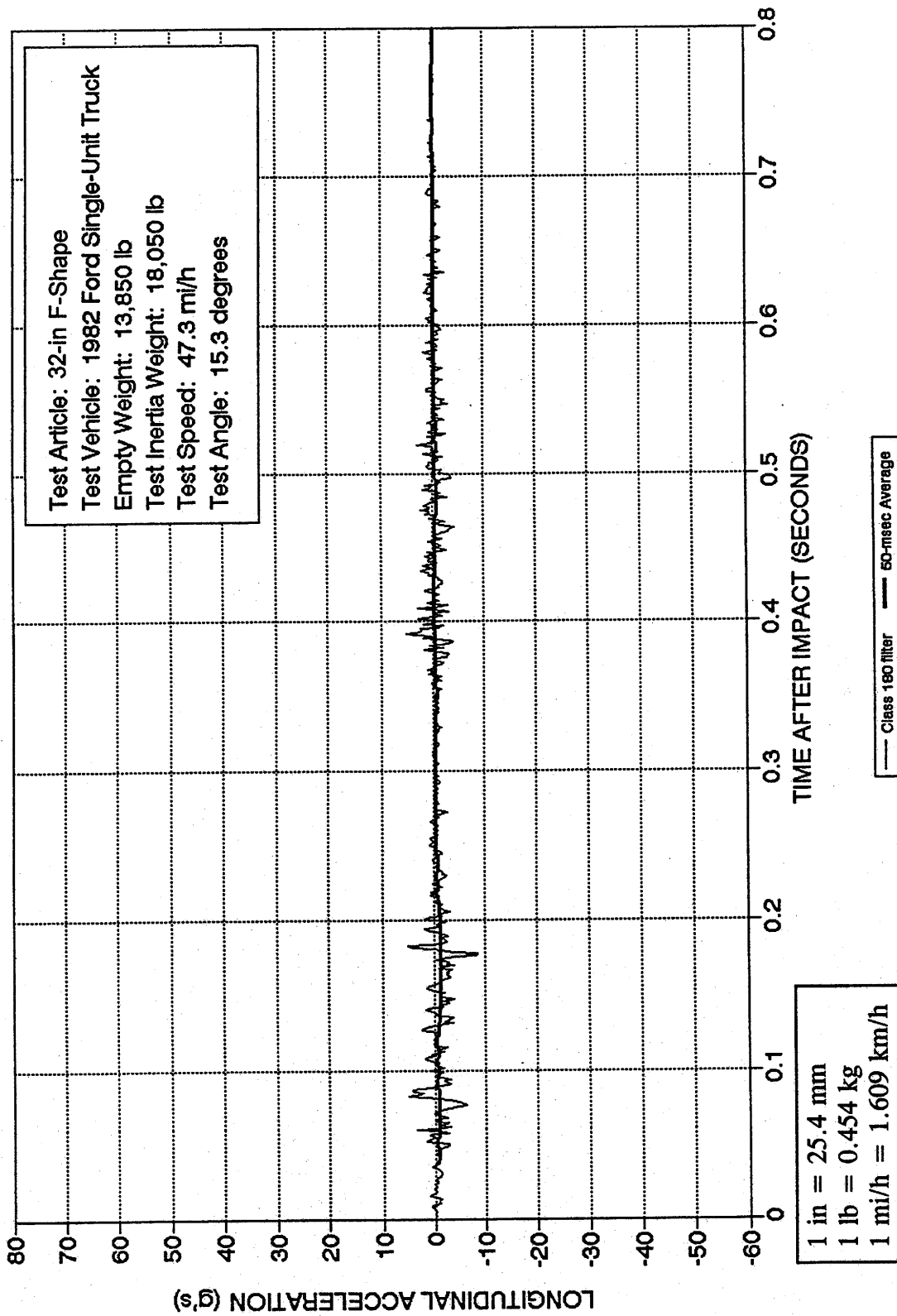
Figure 56. Longitudinal accelerometer trace for test 7069-9
(accelerometer located near center-of-gravity).

81

CRASH TEST 7069-9
Accelerometer near center-of-gravity

Test Article: 32-in F-Shape
Test Vehicle: 1982 Ford Single-Unit Truck
Empty Weight: 13,850 lb
Test Inertia Weight: 18,050 lb
Test Speed: 47.3 mi/h
Test Angle: 15.3 degrees

— Class 180 filter — 50-msec Average

1 in = 25.4 mm
1 lb = 0.454 kg
1 mi/h = 1.609 km/h

LATERAL ACCELERATION (g's)

TIME AFTER IMPACT (SECONDS)
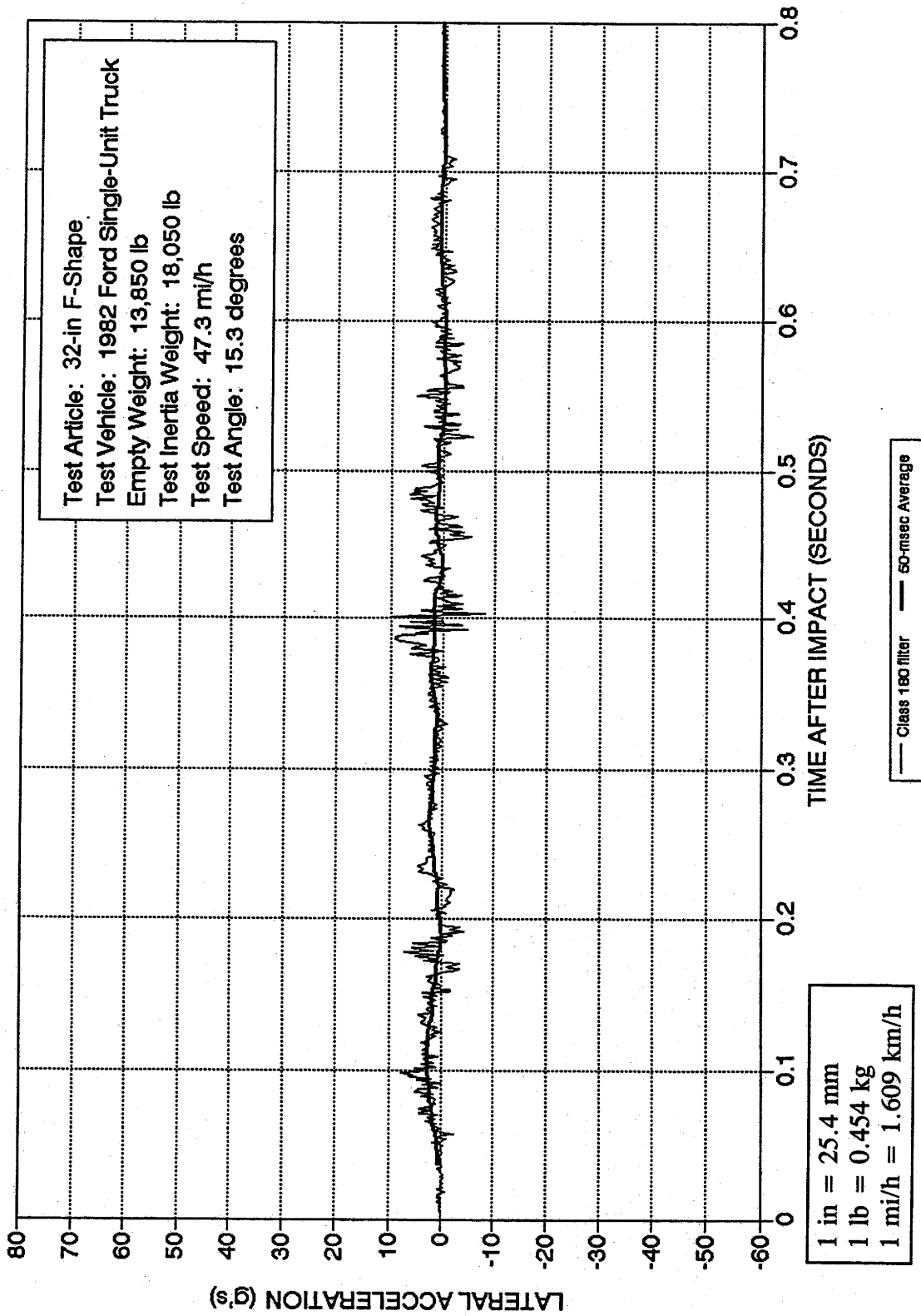
Figure 57. Lateral accelerometer trace for test 7069-9
(accelerometer located near center-of-gravity).
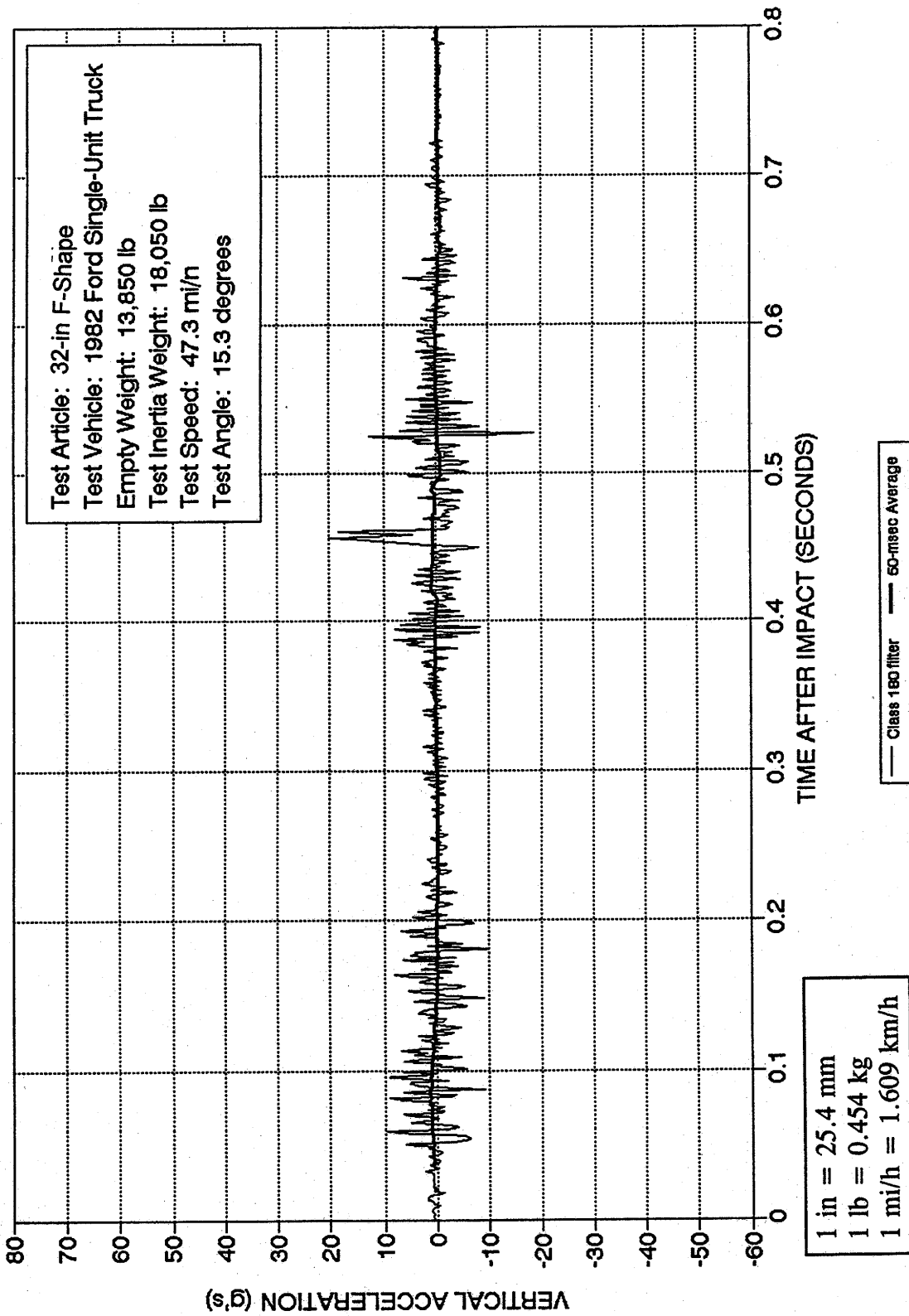
Figure 58. Vertical accelerometer trace for test 7069-9 (accelerometer located near center-of-gravity).
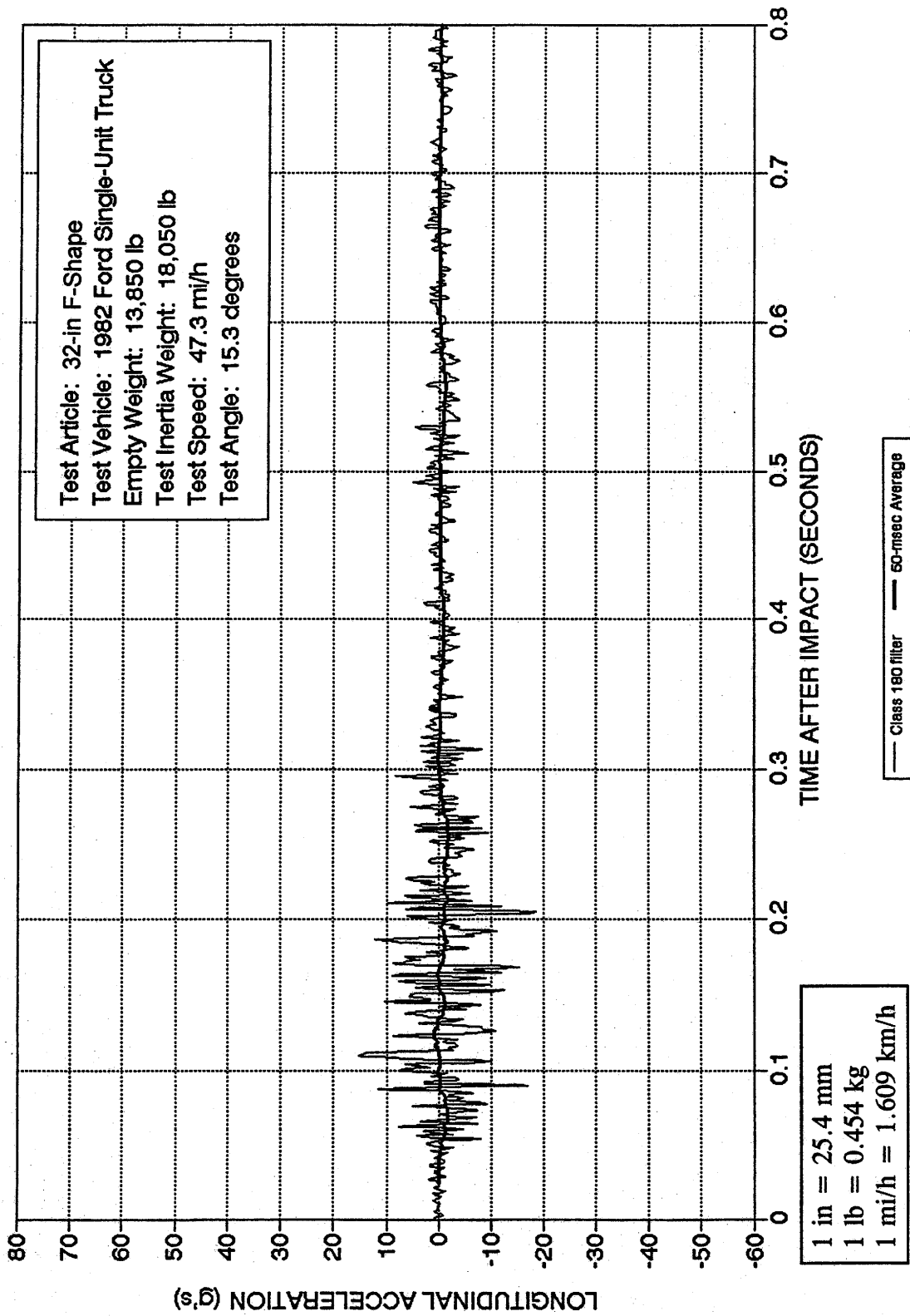
Figure 59. Longitudinal accelerometer trace for test 7069-9 (accelerometer located at front of vehicle).

CRASH TEST 7069-9
Accelerometer at front of vehicle

Test Article: 32-in F-Shape
Test Vehicle: 1982 Ford Single-Unit Truck
Empty Weight: 13,850 lb
Test Inertia Weight: 18,050 lb
Test Speed: 47.3 mi/h
Test Angle: 15.3 degrees

1 in = 25.4 mm
1 lb = 0.454 kg
1 mi/h = 1.609 km/h

— Class 180 filter   — 50-msec Average

LATERAL ACCELERATION (g's)

TIME AFTER IMPACT (SECONDS)
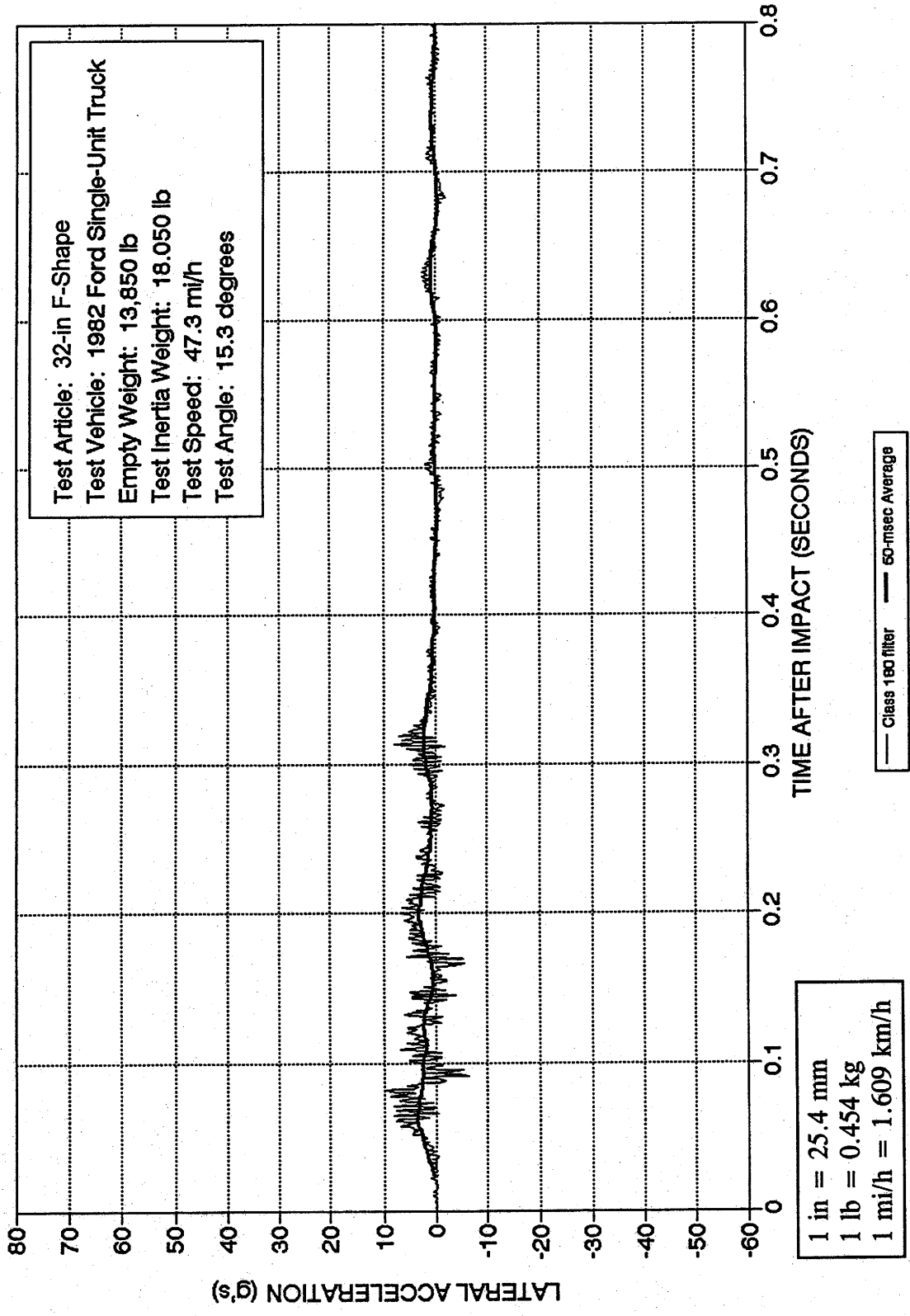
Figure 60. Lateral accelerometer trace for test 7069-9
(accelerometer located at front of vehicle).

85
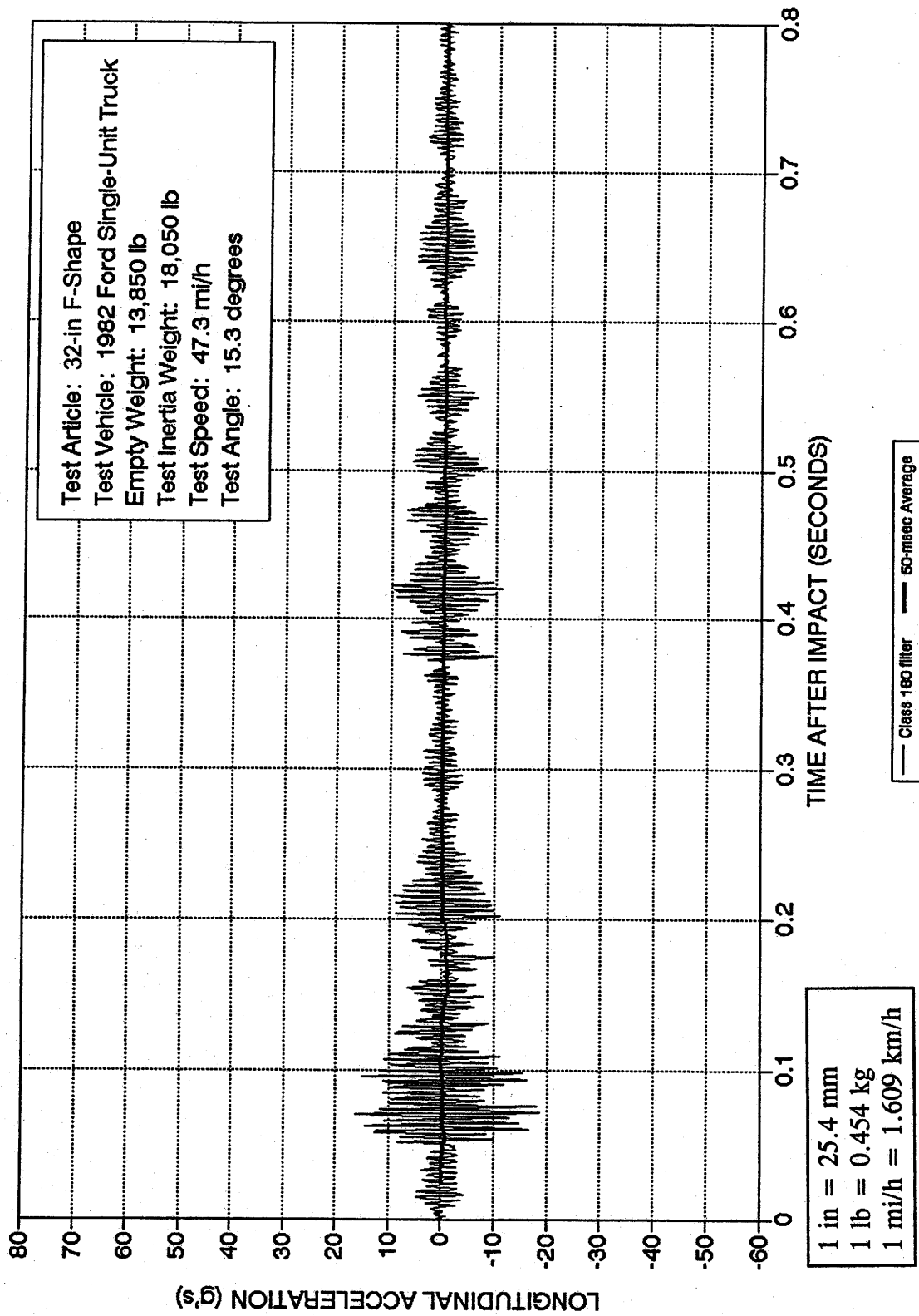
Figure 61. Longitudinal accelerometer trace for test 7069-9 (accelerometer located at rear of vehicle).

CRASH TEST 7069-9
Accelerometer at rear of vehicle

Test Article: 32-in F-Shape
Test Vehicle: 1982 Single-Unit Truck
Empty Weight: 13,850 lb
Test Inertia Weight: 18,050 lb
Test Speed: 47.3 mi/h
Test Angle: 15.3 degrees

LATERAL ACCELERATION (g's)

TIME AFTER IMPACT (SECONDS)

— Class 180 filter   — 50-msec Average

1 in = 25.4 mm
1 lb = 0.454 kg
1 mi/h = 1.609 km/h
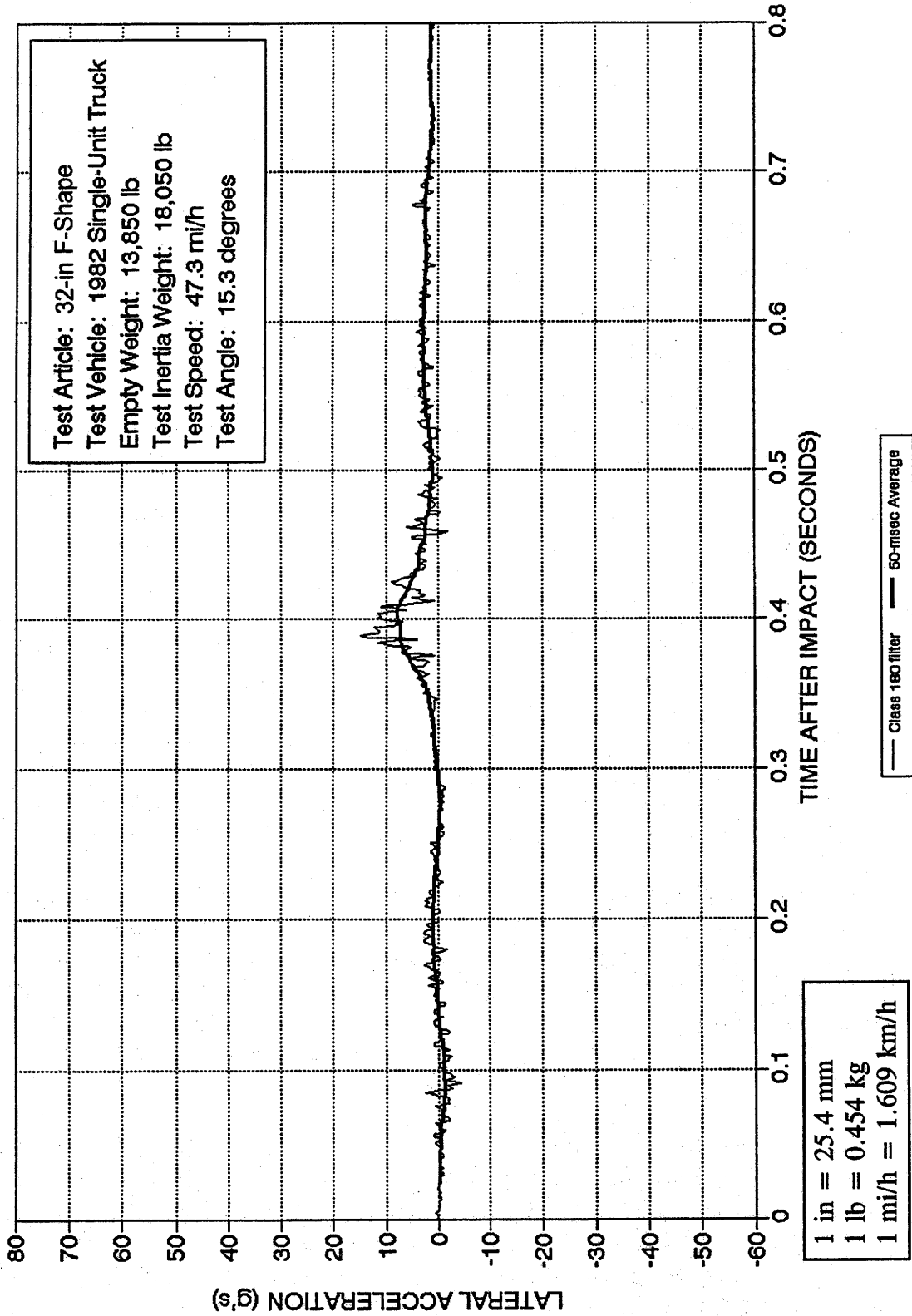
Figure 62. Lateral accelerometer trace for test 7069-9 (accelerometer located at rear of vehicle).

TEST 7069-11

Test Description

The 1982 Ford 7000 single-unit truck (figures 63 and 64) was directed into the 32-in (813-mm) F-shape bridge railing (figure 65) using a remote control guidance system. The empty weight of the vehicle was 18,000 lb (8 172 kg) and its test inertia weight was 18,000 lb (8 172 kg). The height to the lower edge of the vehicle bumper was 18.75 in (476 mm) and it was 28.75 in (730 mm) to the top of the bumper. Other dimensions and information on the test vehicle are given in figures 66 and 67. The vehicle was free-wheeling and unrestrained just prior to impact.

The speed of the vehicle at impact was 52.1 mi/h (83.8 km/h) and the angle of impact was 14.8 degrees. The vehicle impacted the bridge railing at midlength. At approximately 0.022 s after impact the right front wheel began to ride up the face of the bridge railing, and at 0.132 s the left front tire began to leave the ground. The vehicle began to redirect at 0.144 s as the rear end began to slide toward the bridge railing. At 0.240 s the left rear wheels left the ground, and at 0.350 s the rear of the vehicle slapped the bridge railing. By approximately 0.524 s the vehicle became parallel with the railing and was continuing to roll to the right. As the vehicle continued along the railing, the lower edge of the bed rode along the top of the railing. A maximum roll angle of 31 degrees was achieved at about 0.683 s. The vehicle slid off the end of the bridge railing at approximately 1.346 s after impact. The brakes were applied and the vehicle subsequently came to rest 231 ft (70 m) downstream.

As can be seen in figure 68, the railing received cosmetic damage and some scraping. There were tire marks on the face of the bridge railing and along the top. The top of the bridge railing was scraped along the remaining length from the lower edge of the bed of the truck. The vehicle was in contact with the bridge railing for 39 ft (12 m).

The vehicle sustained extensive damage to the right side as shown in figure 69. Maximum crush at the right front corner at bumper height was 20.0 (508 mm). The front axle was torn loose which caused damage to the springs, shackles, U-bolts, and tie rods. The steering arm and cylinder were damaged and the oil pan was dented. Also, the fuel tank broke loose from the truck.

Test Results

Impact speed was 52.1 mi/h (83.8 km/h) and the angle of impact was 14.8 degrees. The exit speed was not available. Exit angle was about 0 degrees. The effective coefficient of friction was calculated to be 0.12. Occupant impact velocity was 5.7 ft/s (1.7 m/s) in the longitudinal direction and 8.2 ft/s (2.5 m/s) in the lateral direction. The highest 0.010-s occupant ridedown accelerations were 1.3 g (longitudinal) and 5.4 g (lateral). These data and other pertinent information from the test are summarized in figure 70 and table 7. Sequential photographs are shown in figures 71 and 72. Vehicular angular displacements are displayed in figure 73. Vehicle accelerations versus time traces filtered with SAE J211

filters are presented in figures 74 through 80. These data were further analyzed to obtain 0.050-s average accelerations versus time. The maximum 0.050-s averages were -1.4 g (longitudinal) and 3.9 g (lateral).

Conclusions

The 32-in (813-mm) F-shape bridge railing contained and smoothly redirected the vehicle with no lateral movement of the bridge railing. There were no debris or detached elements. There was no intrusion into the occupant compartment. The vehicle trajectory at loss of contact indicated minimum intrusion into adjacent traffic lanes. The vehicle remained upright and marginally stable during the entire test period. See table 7 for a more detailed description.
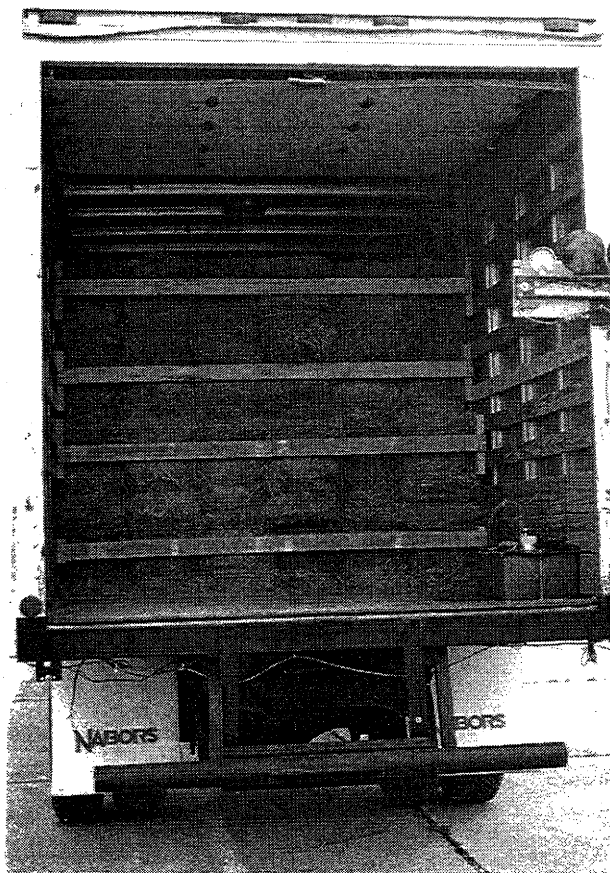
Figure 63.   Vehicle before test 7069-11.
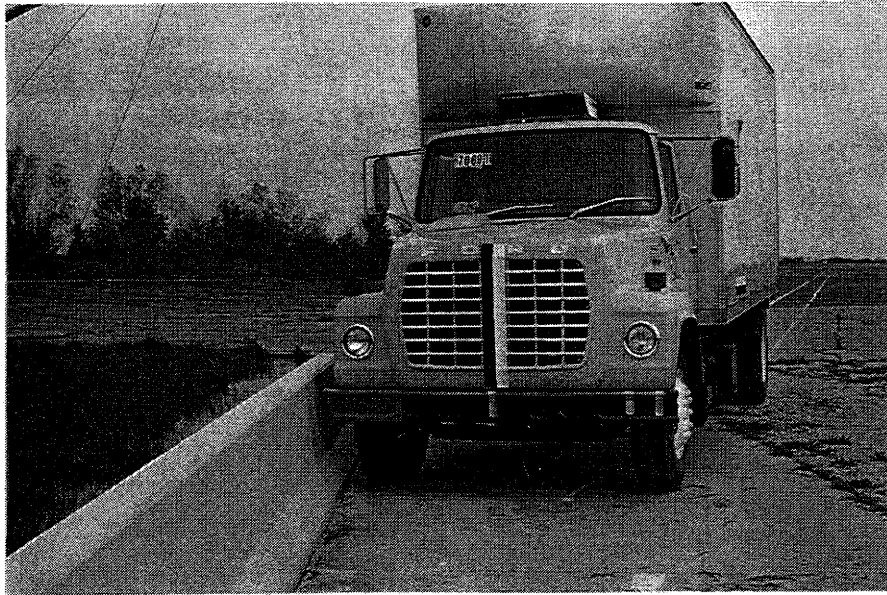
Figure 64. Vehicle/bridge railing geometrics for test 7069-11.
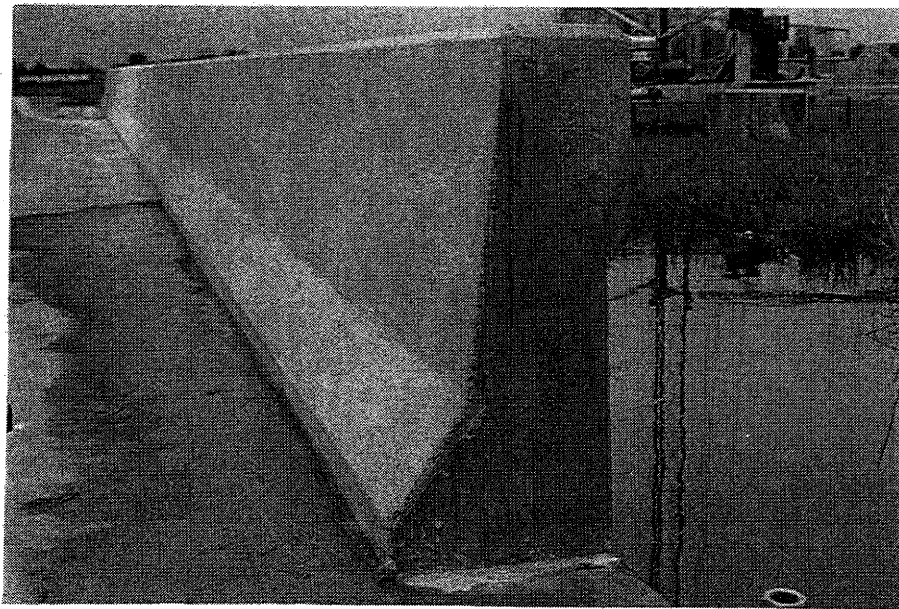
Figure 65. 32-in (813-mm) F-shape bridge railing before test 7069-11.
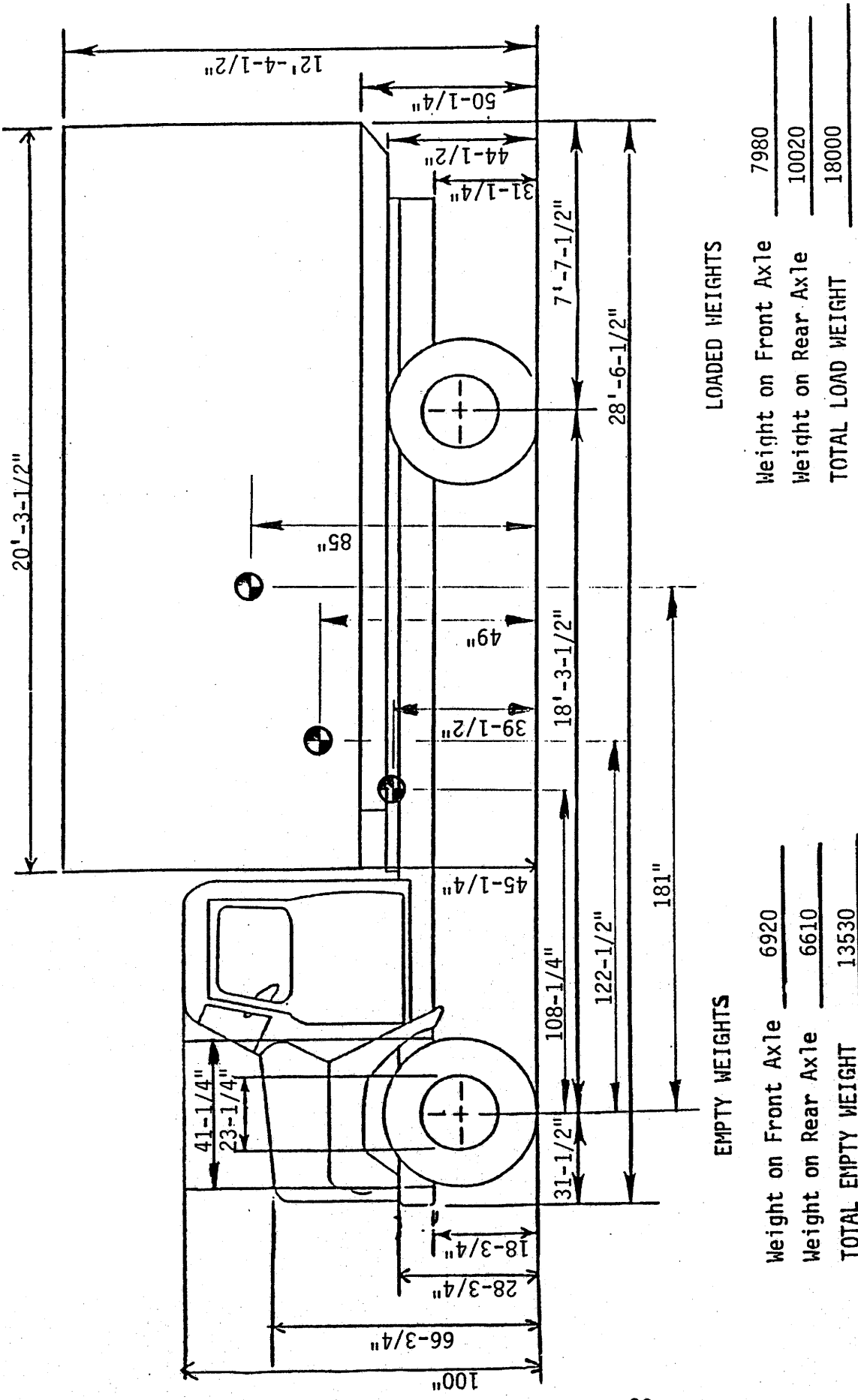
EMPTY WEIGHTS

Weight on Front Axle	6920
Weight on Rear Axle	6610
TOTAL EMPTY WEIGHT	13530

LOADED WEIGHTS

Weight on Front Axle	7980
Weight on Rear Axle	10020
TOTAL LOAD WEIGHT	18000

1 in = 25.4 mm

Figure 66. Vehicle properties for test 7069-11.

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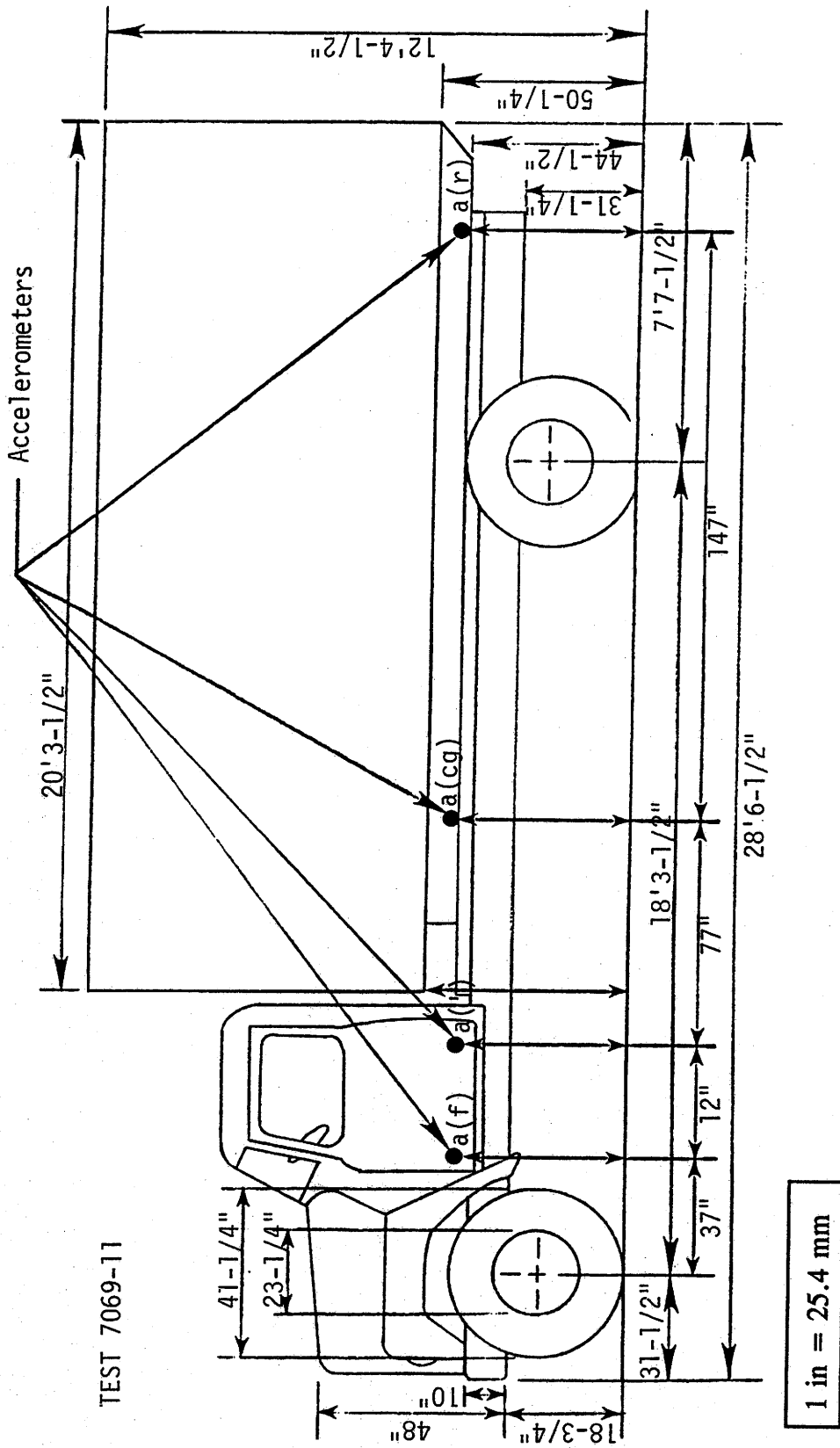
Figure 67. Accelerometer locations for test 7069-11.

94
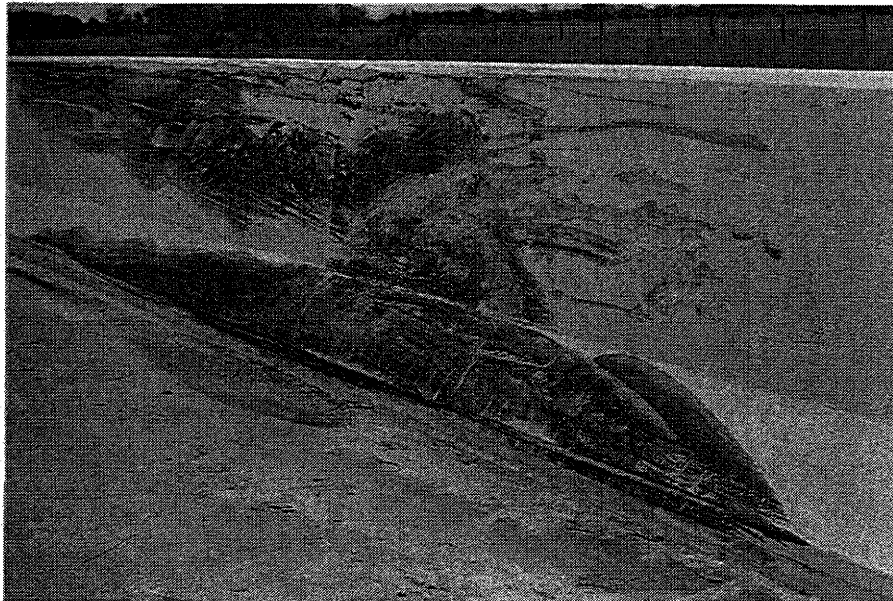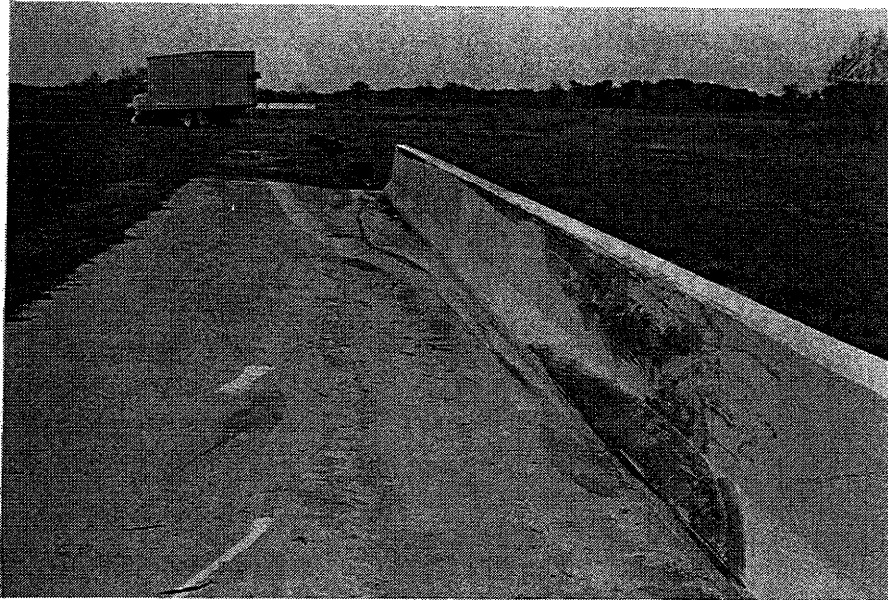
Figure 68. 32-in (813-mm) bridge railing after test 7069-11.

Figure 69.   Vehicle after test 7069-11.

0.000 s   0.158 s   0.474 s   0.790 s

Test No.	7069-11
Date	3/30/88
Test Installation . . .	32-in (813-mm) F-Shape Bridge Railing
Installation Length . .	100 ft (30 m)
Vehicle	1982 Ford 7000 Single-Unit Truck
Vehicle Weight	
Empty Weight	13,530 lb (6,145 kg)
Test Inertia	18,000 lb (8,172 kg)
Maximum Vehicle Crush .	20.0 in (508 mm)

Impact Speed. . . .	52.1 mi/h (83.8 km/h)
Impact Angle.	14.8 deg
Exit Speed	Not Available
Exit Trajectory . .	0 deg
Vehicle Accelerations	
(Max. 0.050-sec Avg)	
Longitudinal. . .	-1.4 g
Lateral	3.9 g
Occupant Impact Velocity	
Longitudinal. . .	5.7 ft/s (1.7 m/s)
Lateral	8.2 ft/s (2.5 m/s)
Occupant Ridedown Accelerations	
Longitudinal. . .	1.3 g
Lateral	5.4 g

(1 in = 25.4 mm)

Figure 70. Summary of results for test 7069-11.

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Table 7. Evaluation of crash test no. 7069-11.
{32-in (81 cm) F-Shape Bridge Railing [18,000 lb (8 172 kg)|52.1 mi/h (83.8 km/h)|14.8 degrees]}

CRITERIA	TEST RESULTS	PASS/FAIL*
A. Must contain vehicle	Vehicle was contained	Pass
B. Debris shall not penetrate passenger compartment	No debris penetrated passenger compartment	Pass
C. Passenger compartment must have essentially no deformation	Acceptable information	Pass
D. Vehicle must remain upright	Vehicle remained upright	Pass
E. Must smoothly redirect the vehicle	Vehicle was smoothly redirected	Pass
F. Effective coefficient of friction _μ_ Assessment 0 - .25 Good .26 - .35 Fair > .35 Marginal	_μ_ Assessment .12 Good	Pass
G. Shall be less than Occupant Impact Velocity - ft/s (m/s) Longitudinal Lateral 30 (9.2) 25 (7.6) Occupant Ridedown Accelerations - g's Longitudinal Lateral 15 15	Occupant Impact Velocity - ft/s (m/s) Longitudinal Lateral 5.7 (1.7) 8.2 (2.5) Occupant Ridedown Accelerations - g's Longitudinal Lateral 1.3 5.4	N/A N/A
H. Exit angle shall be less than 12 degrees	about 0 degrees	Pass

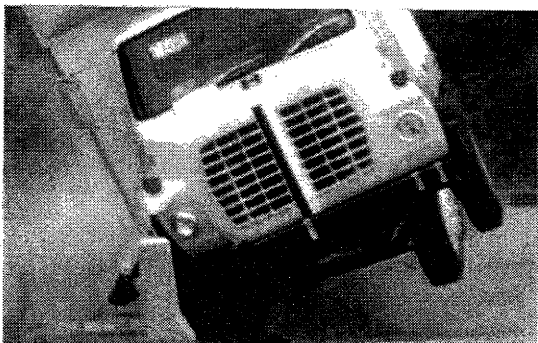* A, B, C, and D are required. E, F, and H are desired. G is not applicable for this test. (See table 5)
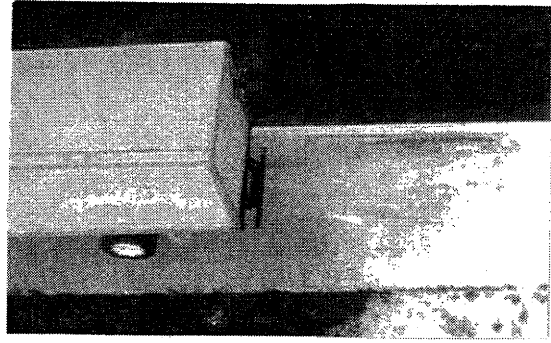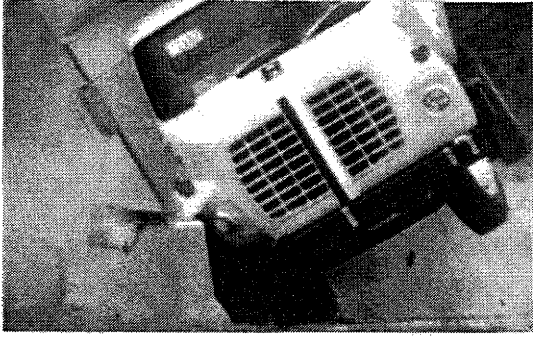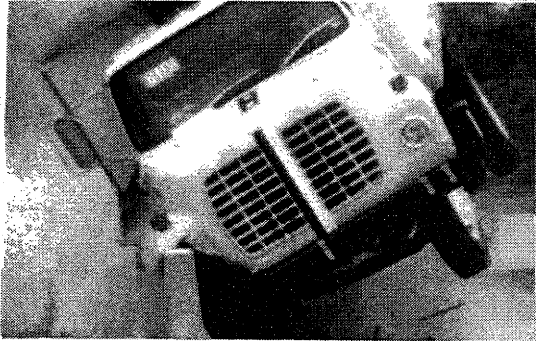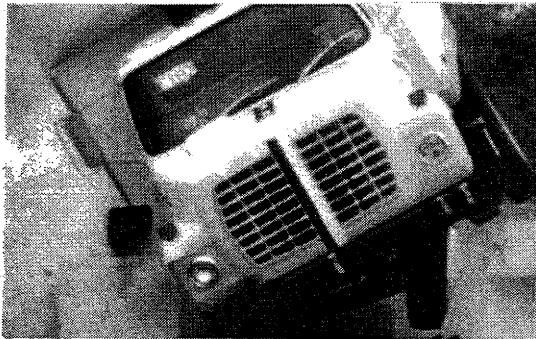
98

0.000 s

0.158 s

0.316 s

0.474 s

Figure 71.   Sequential photographs for test 7069-11.
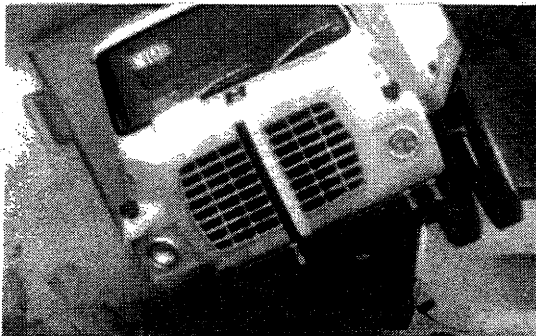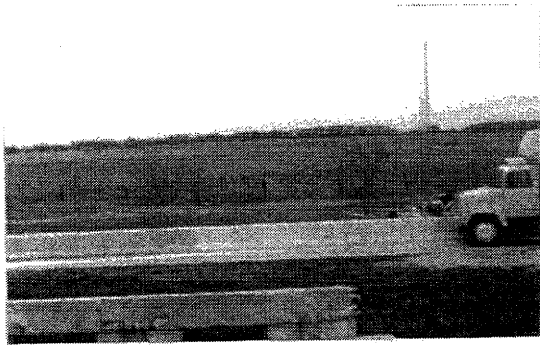
99

0.632 s

0.790 s
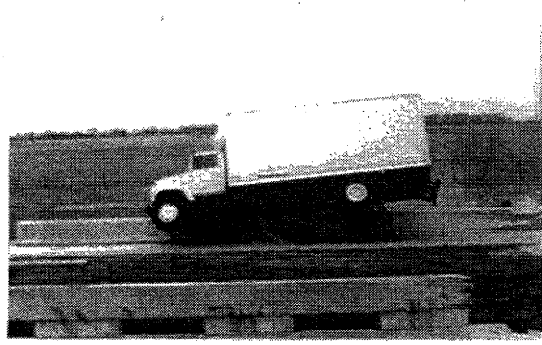
Out of view

0.951 s

Out of view

1.111 s

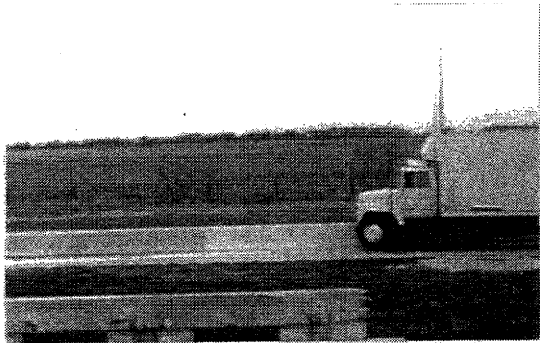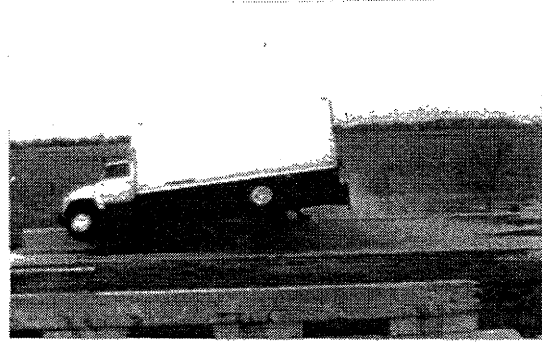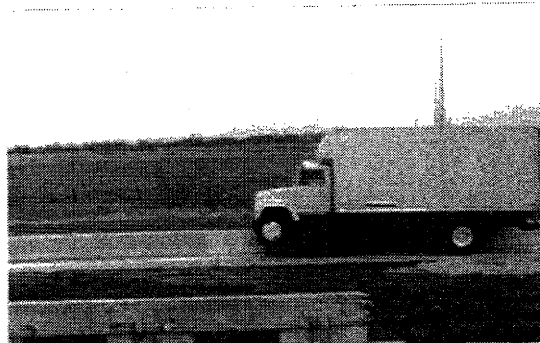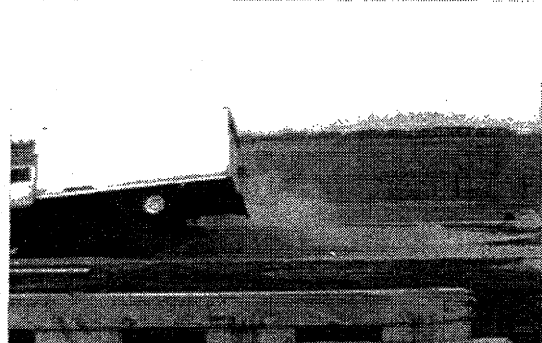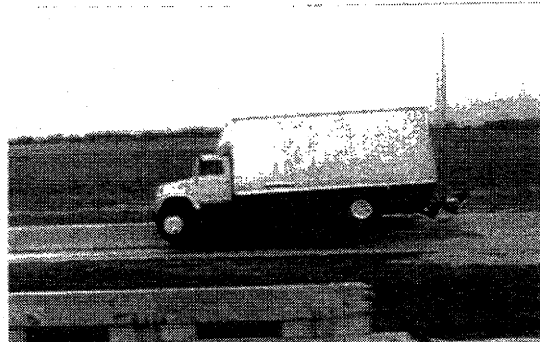Figure 71. Sequential photographs for test 7069-11 (continued).

0.000 s

0.632 s

0.158 s

0.790 s

0.316 s

0.951 s

0.474 s
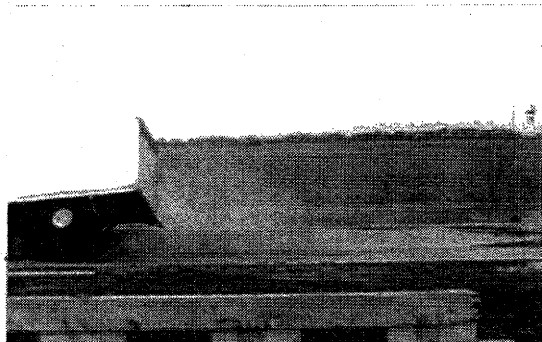
1.111 s

Figure 72. Perpendicular sequential photographs for test 7069-11.
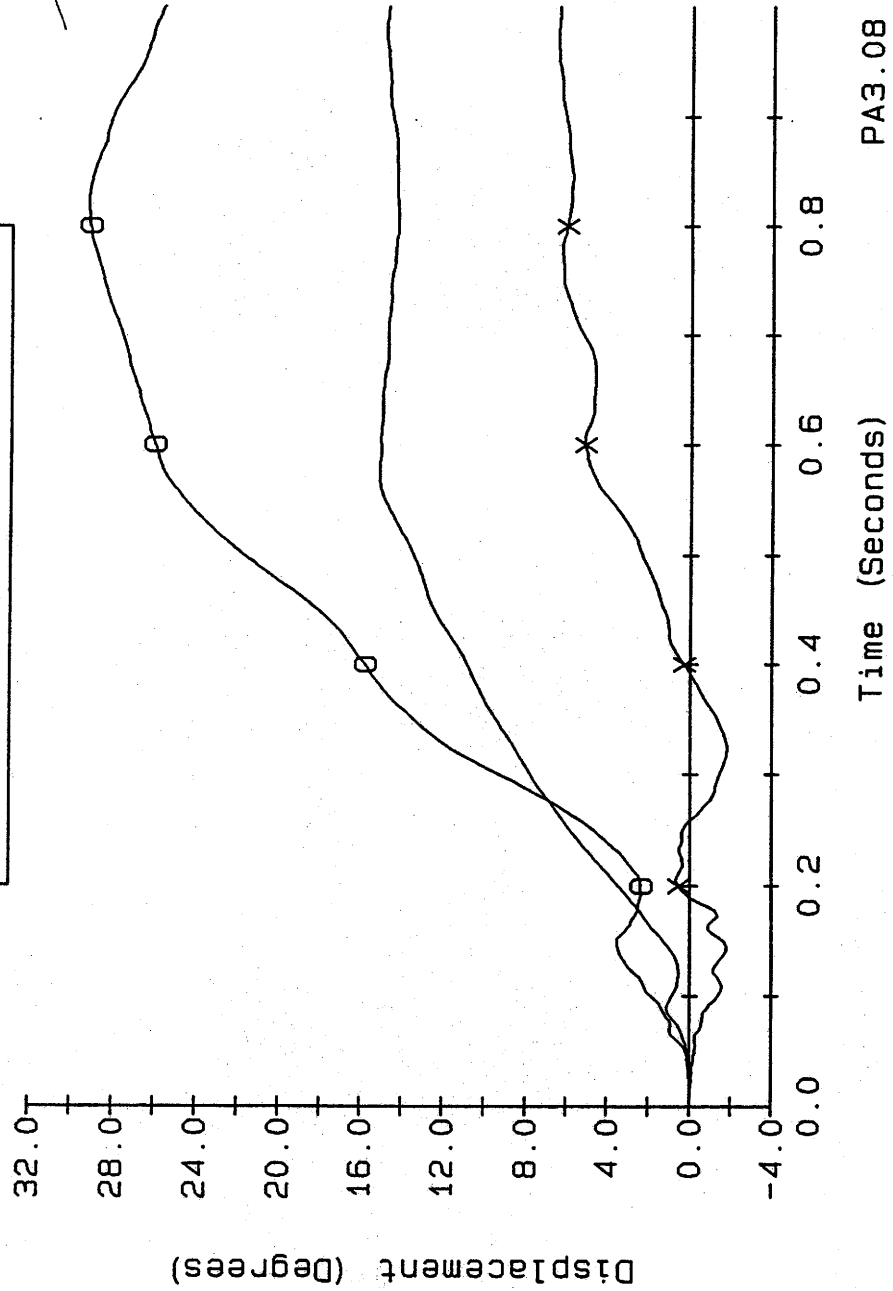
101
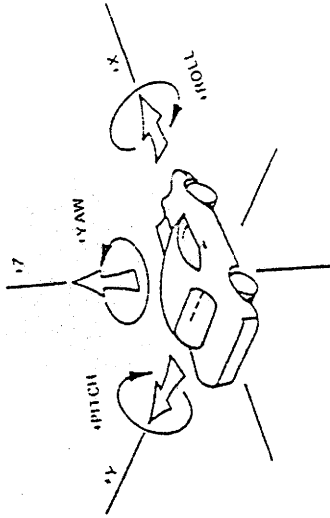
Figure 73. Vehicle angular displacements for test 7069-11.

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CRASH TEST 7069-11
Accelerometer near center-of-gravity

Test Article: 32-in F-Shape
Test Vehicle: 1982 Ford Single-Unit Truck
Empty Weight: 13,530 lb
Test Inertia Weight: 18,000 lb
Test Speed: 52.1 mi/h
Test Angle: 14.8 degrees

1 in = 25.4 mm
1 lb = 0.454 kg
1 mi/h = 1.609 km/h

— Class 180 filter   — 50-msec Average

Figure 74. Vehicle longitudinal accelerometer trace for test 7069-11
(accelerometer located near center-of-gravity).

CRASH TEST 7069-11
Accelerometer near center-of-gravity

Test Article: 32-in F-Shape
Test Vehicle: 1982 Ford Single-Unit Truck
Empty Weight: 13,530 lb
Test Inertia Weight: 18,000 lb
Test Speed: 52.1 mi/h
Test Angle: 14.8 degrees

1 in = 25.4 mm
1 lb = 0.454 kg
1 mi/h = 1.609 km/h

LATERAL ACCELERATION (g's)

TIME AFTER IMPACT (SECONDS)

Class 180 filter   50-msec Average

Figure 75. Vehicle lateral accelerometer trace for test 7069-11
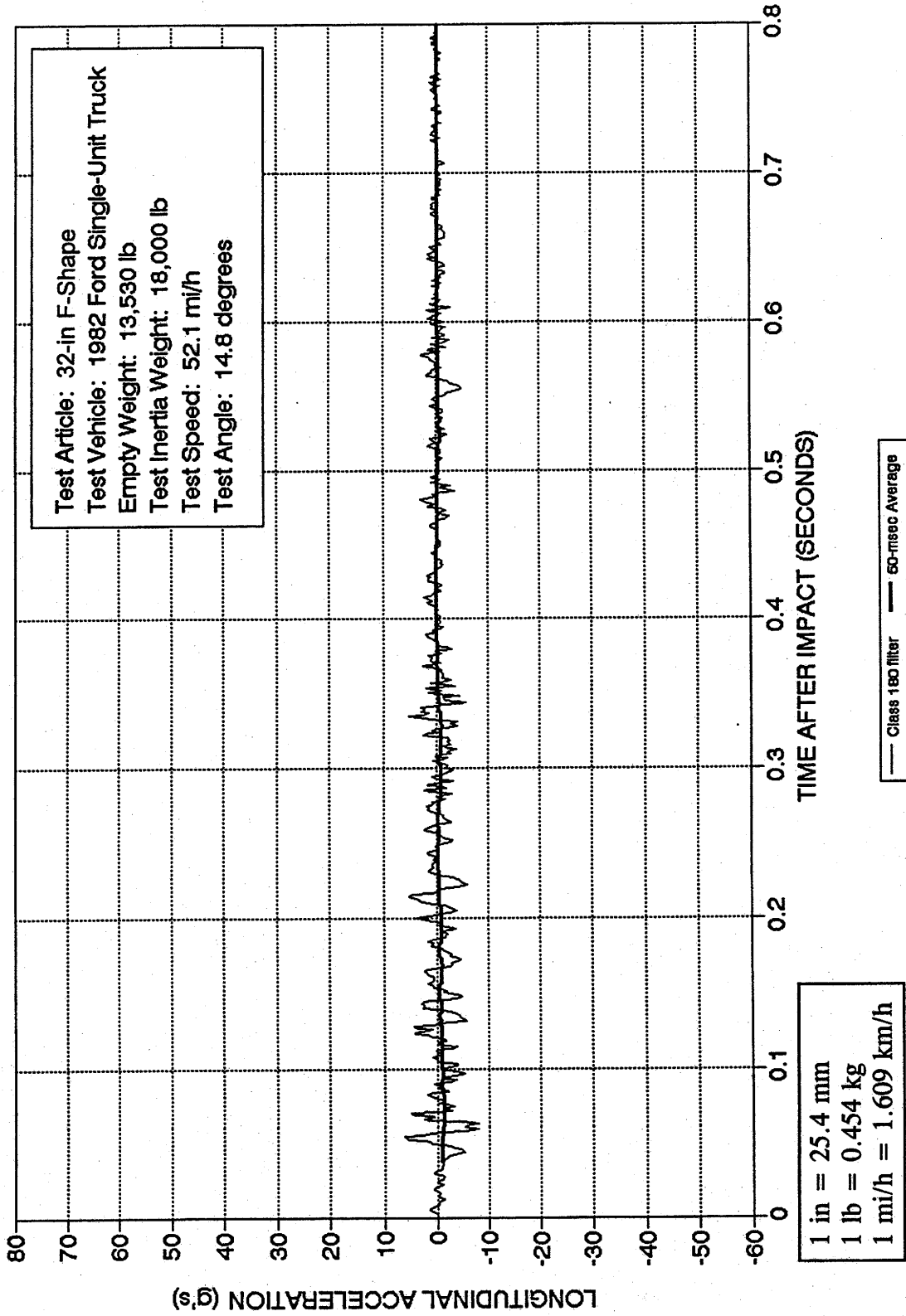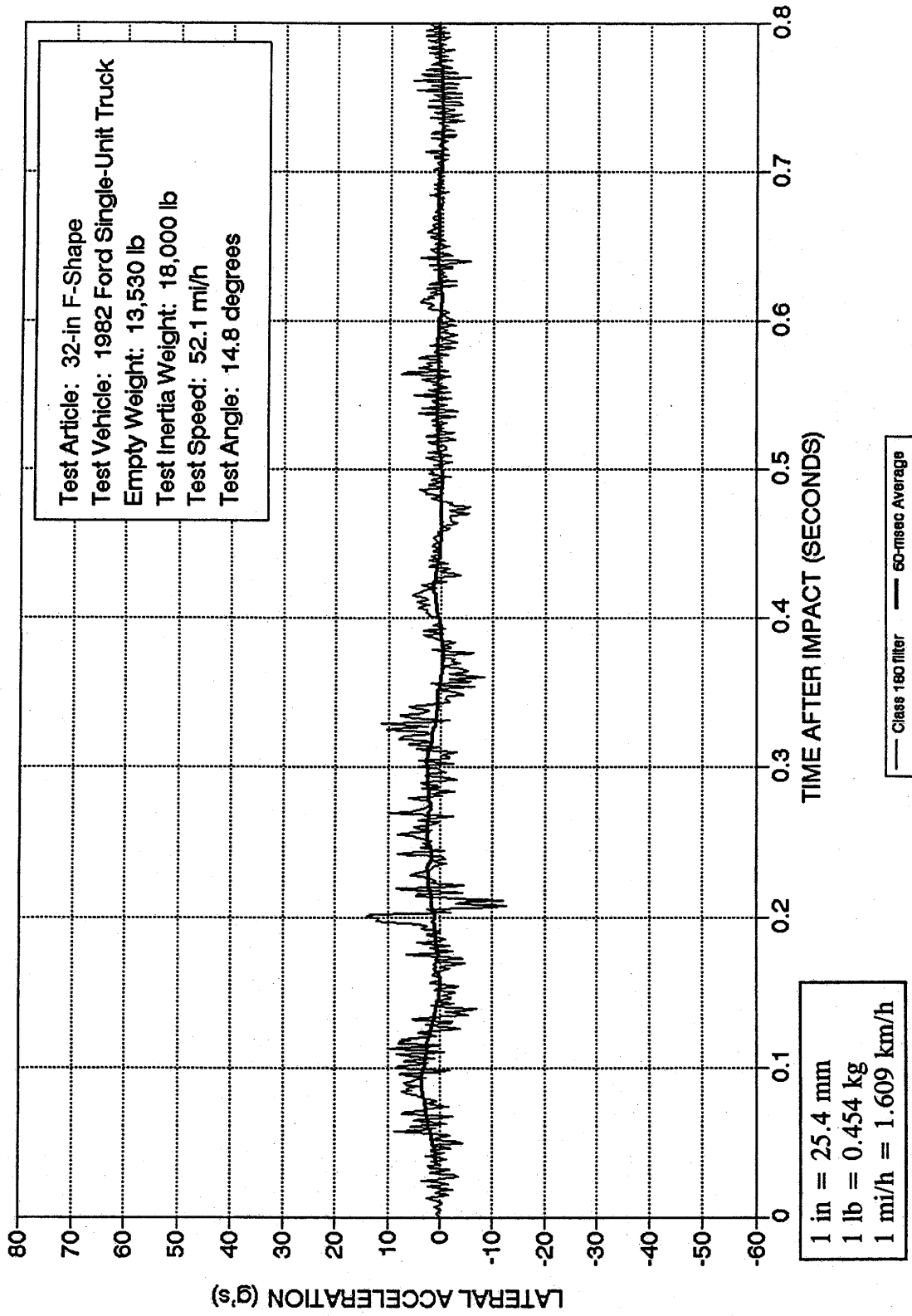(accelerometer located near center-of-gravity).

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Figure 76. Vehicle vertical accelerometer trace for test 7069-11 (accelerometer located near center-of-gravity).

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CRASH TEST 7069-11
Accelerometer at front of vehicle

Test Article: 32-in F-Shape
Test Vehicle: 1982 Ford Single-Unit Truck
Empty Weight: 13,530 lb
Test Inertia Weight: 18,000 lb
Test Speed: 52.1 mi/h
Test Angle: 14.8 degrees

1 in = 25.4 mm
1 lb = 0.454 kg
1 mi/h = 1.609 km/h

— Class 180 filter — 50-msec Average

TIME AFTER IMPACT (SECONDS)

LONGITUDINAL ACCELERATION (g's)

Figure 77. Vehicle longitudinal accelerometer trace for test 7069-11 (accelerometer located at front of vehicle).

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CRASH TEST 7069-11
Accelerometer at front of vehicle

Test Article: 32-in F-Shape
Test Vehicle: 1982 Ford Single-Unit Truck
Empty Weight: 13,530 lb
Test Inertia Weight: 18,000 lb
Test Speed: 52.1 mi/h
Test Angle: 14.8 degrees

1 in = 25.4 mm
1 lb = 0.454 kg
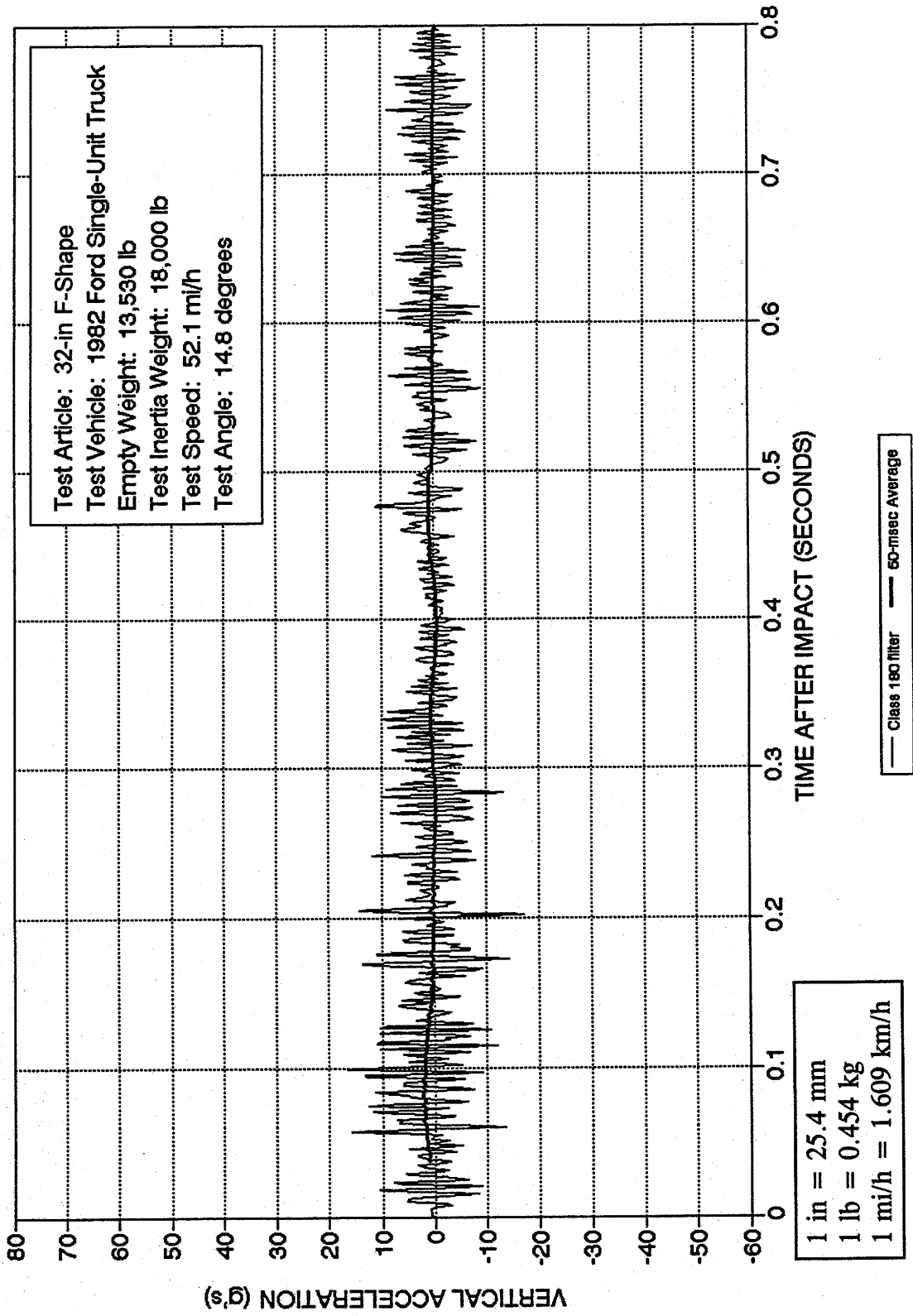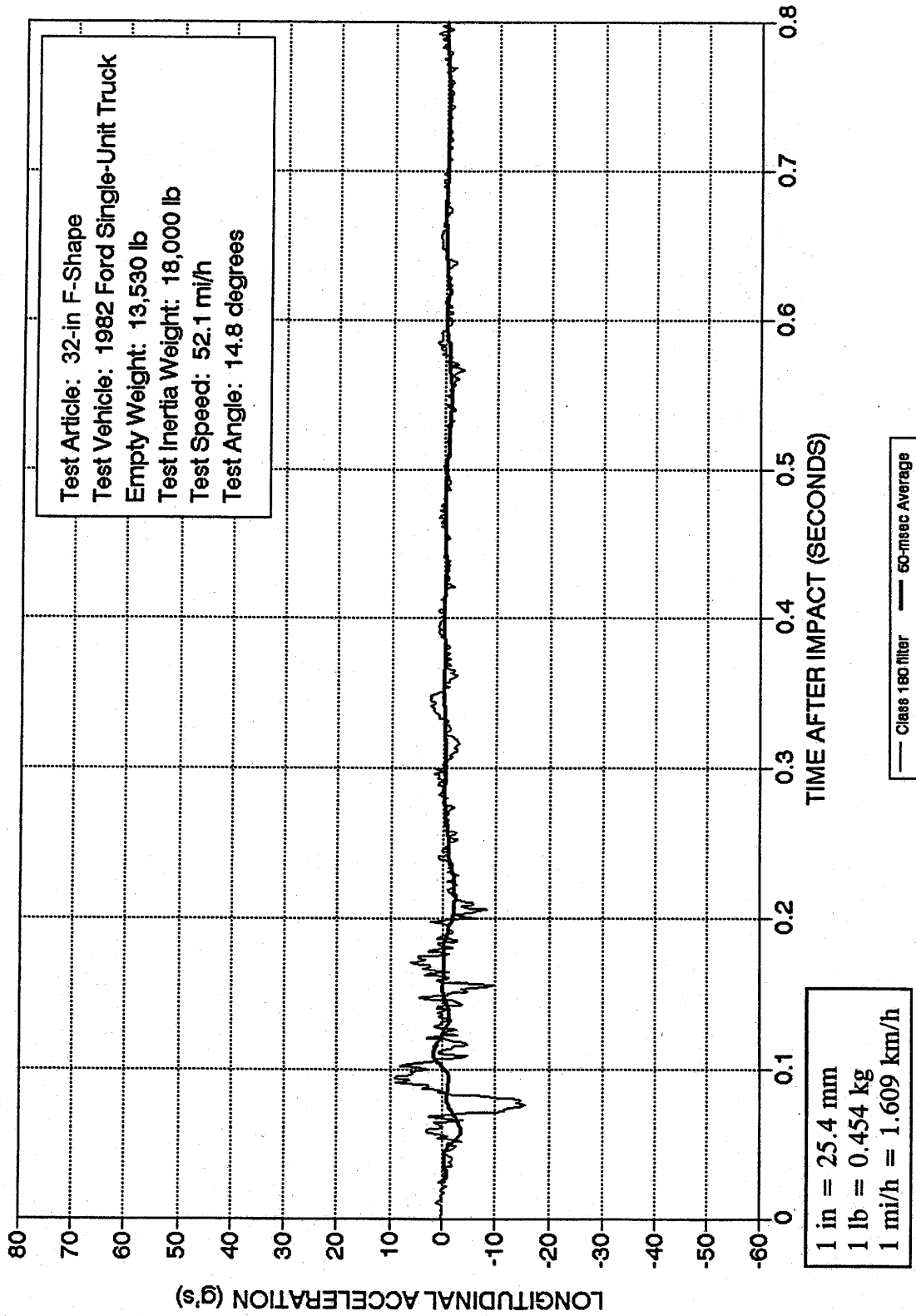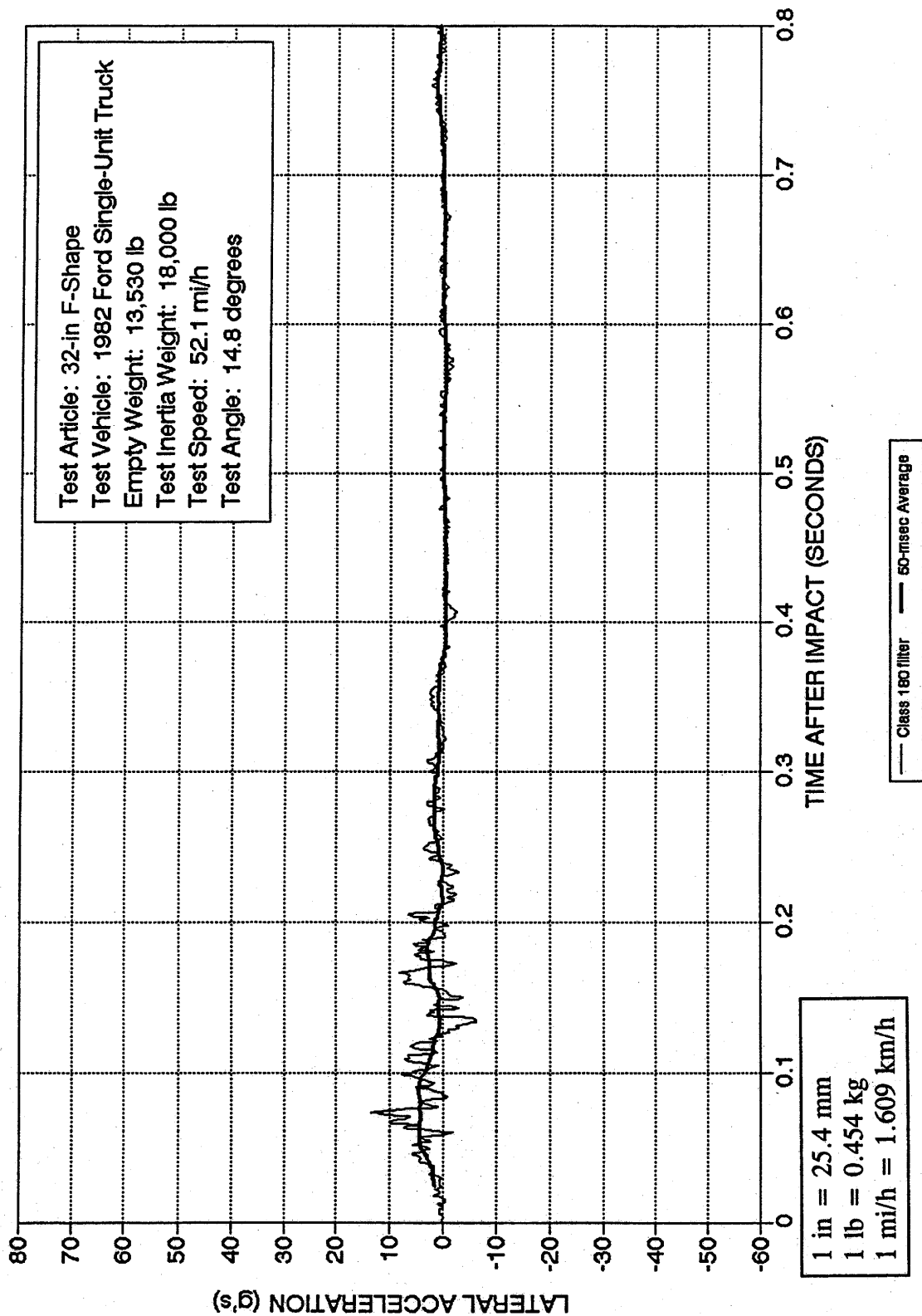1 mi/h = 1.609 km/h

— Class 180 filter   — 50-msec Average

Figure 78. Vehicle lateral accelerometer trace for test 7069-11 (accelerometer located at front of vehicle).

CRASH TEST 7069-11
Accelerometer at rear of vehicle

Test Article: 32-in F-Shape
Test Vehicle: 1982 Ford Single-Unit Truck
Empty Weight: 13,530 lb
Test Inertia Weight: 18,000 lb
Test Speed: 52.1 mi/h
Test Angle: 14.8 degrees

1 in = 25.4 mm
1 lb = 0.454 kg
1 mi/h = 1.609 km/h

Class 180 filter   50-msec Average

LONGITUDINAL ACCELERATION (g's)
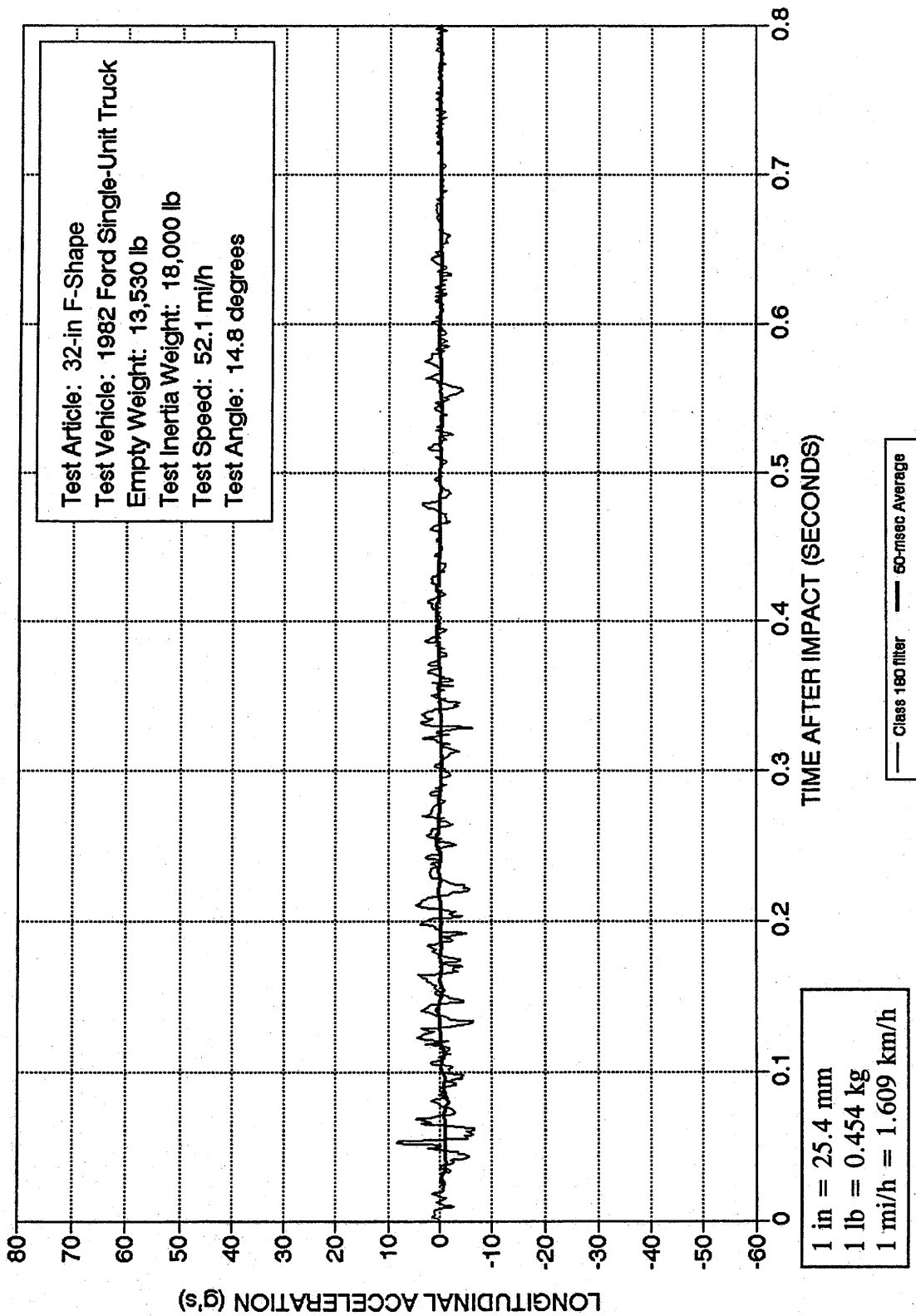
TIME AFTER IMPACT (SECONDS)

Figure 79. Vehicle longitudinal accelerometer trace for test 7069-11 (accelerometer located at rear of vehicle).

CRASH TEST 7069-11
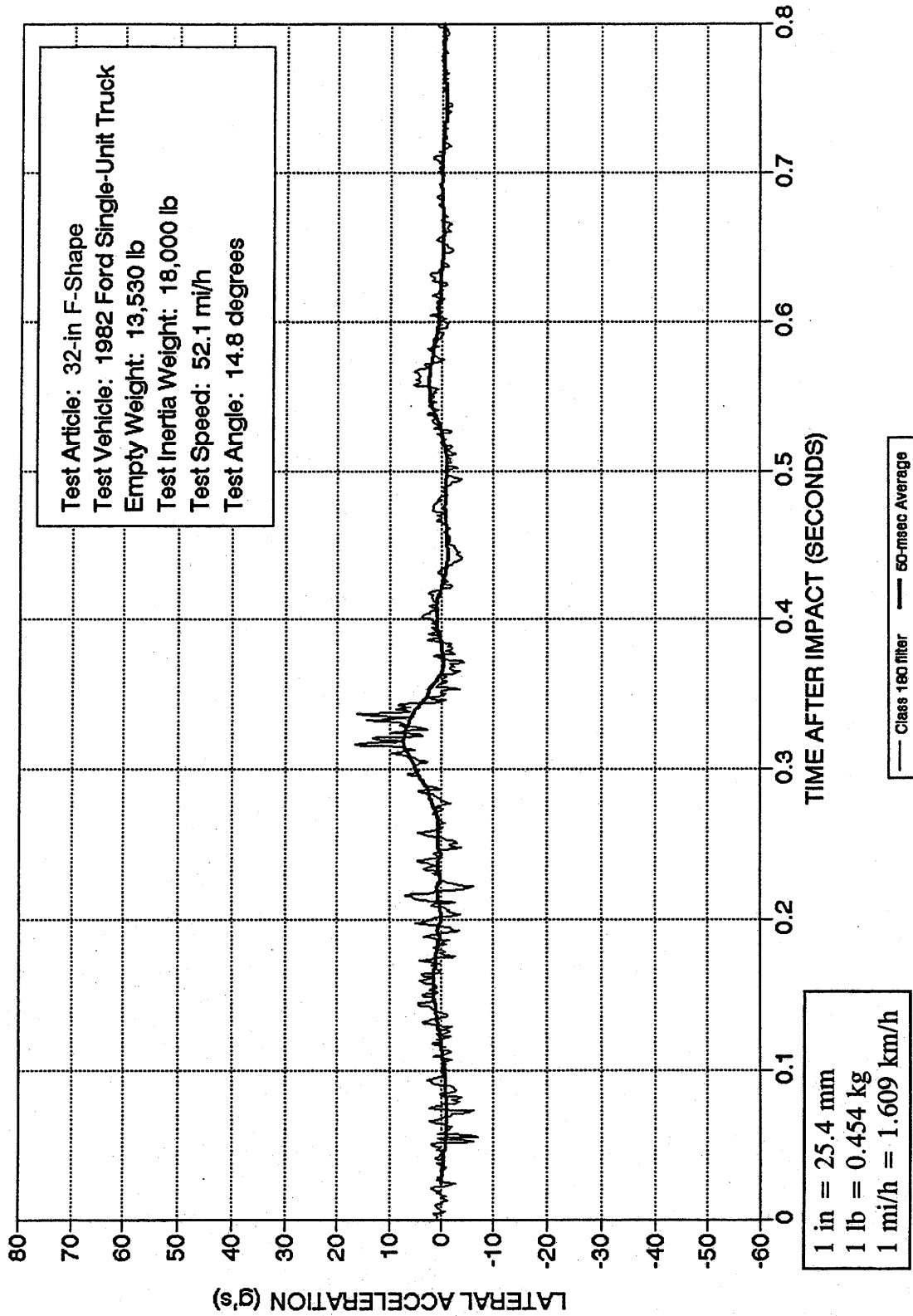## Accelerometer at rear of vehicle

Test Article: 32-in F-Shape
Test Vehicle: 1982 Ford Single-Unit Truck
Empty Weight: 13,530 lb
Test Inertia Weight: 18,000 lb
Test Speed: 52.1 mi/h
Test Angle: 14.8 degrees

1 in = 25.4 mm
1 lb = 0.454 kg
1 mi/h = 1.609 km/h

—— Class 180 filter   —— 50-msec Average

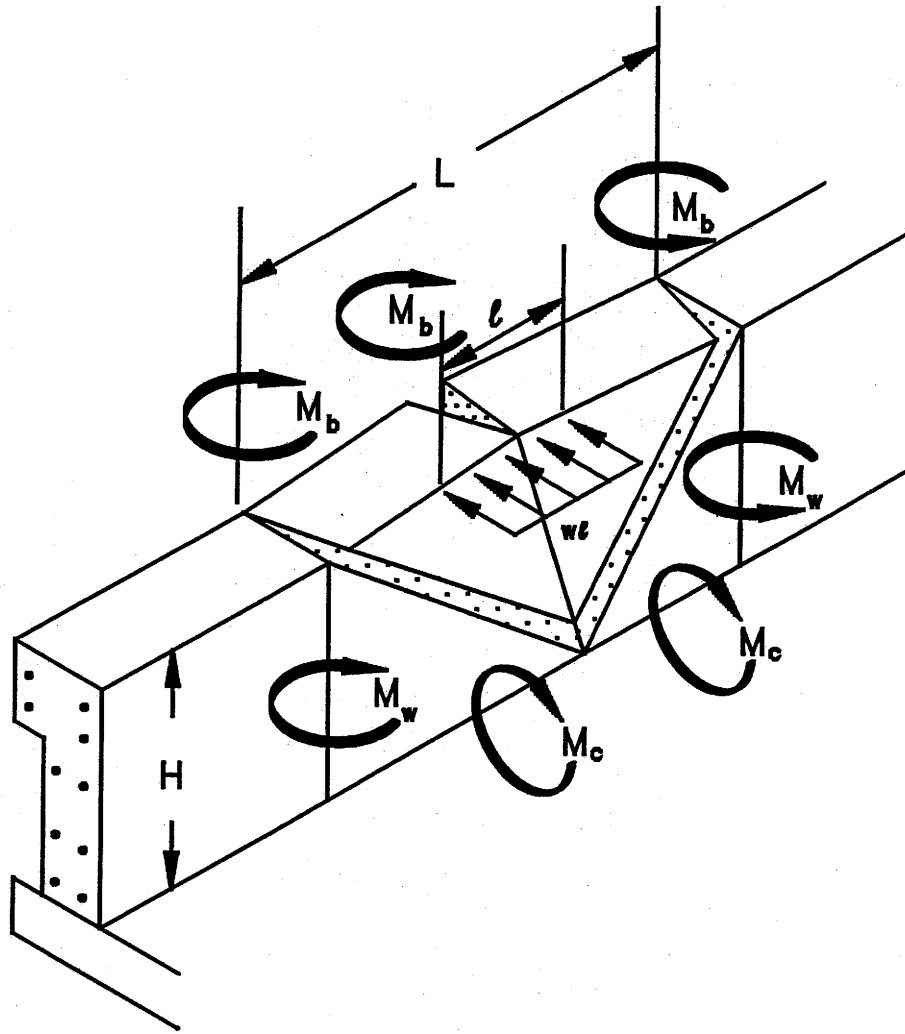LATERAL ACCELERATION (g's)

TIME AFTER IMPACT (SECONDS)

Figure 80. Vehicle lateral accelerometer trace for test 7069-11 (accelerometer located at rear of vehicle).

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4. STRENGTH CALCULATIONS

Analysis of strength of the railing is based on yieldline failure pattern and equations shown in figure 72. Force from a colliding vehicle is idealized as being a uniformly distributed line load extending over 3.5 ft (1.07 m). The load may be applied at any location along the railing. Length of the failure pattern depends on the relative bending moment capacities of various elements of the railing. The computed cantilever moment capacity of parapet, M_c, is 10.6 ft-k/ft (47.2 m-kN/m) and the moment capacity about a vertical axis, M_w, is 4.89 ft-k/ft (21.8 m-kN/m). The additional moment capacity of the stiffening beam along the top of the parapet, M_b, is 6.8 ft-kips (9.2 m-kN). These values result in a length of yieldline pattern of 8.3 ft (211 mm) and the strength of the parapet is 59.1 kips (263 kN) located at the top of the parapet.

$$L = \frac{\ell}{2} + \sqrt{\left(\frac{\ell}{2}\right)^2 + \frac{8H(M_b + M_w H)}{M_c}}$$

$$(w\ell)_{ult} = \frac{8M_b}{L - \frac{\ell}{2}} + \frac{8M_w H}{L - \frac{\ell}{2}} + \frac{M_c L^2}{H\left(L - \frac{\ell}{2}\right)}$$

Figure 81. Yieldline failure pattern for concrete parapet.

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REFERENCES

1.   *Guide Specifications for Bridge Railings*, proposed, American Association of State Highway and Transportation Officials (AASHTO), Washington, DC, April 2, 1987.

2.   *Guide Specifications For Bridge Railings*, American Association of State Highway and Transportation Officials (AASHTO), Washington, DC, 1989.

3.   Hirsch, T. J., "Analytical Evaluation of Texas Bridge Rails to Contain Buses and Trucks," Research Report 230-2, Texas Transportation Institute, Texas A&M University, College Station, TX, August 1978.